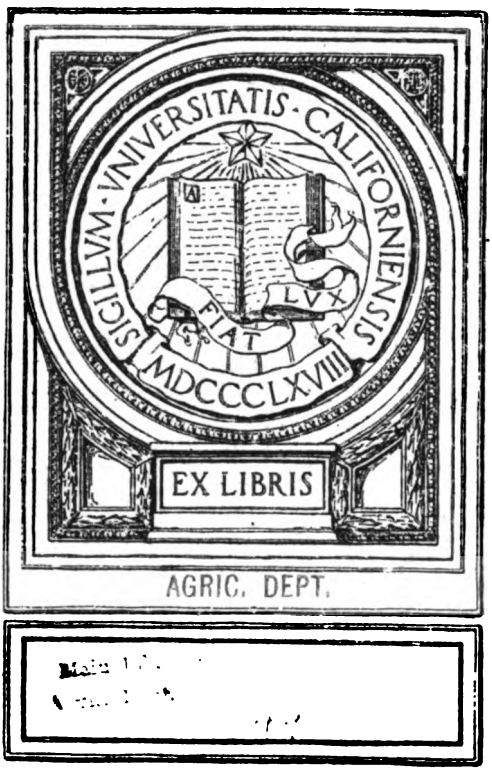
Lake Vieux Desert. View from Upstream.

Lake Vieux Desert. View from Downstream.

Preliminary report on storage reservoirs at the headwaters of ...

Clinton Brown Stewart, Wisconsin. State Board of Forestry, Wisconsin



WISCONSIN STATE BOARD OF FORESTRY
E. M. GRIFFITH, STATE FORESTER.

PRELIMINARY REPORT

ON

STORAGE RESERVOIRS

AT THE

Headwaters of the Wisconsin River and Their Relation to Stream Flow.

BY

C. B. STEWART, Consulting Engineer

FEBRUARY, 1911

MADISON, WIS.,
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MADISON, Wis., Feb. 13th, 1911.

MEMBERS OF THE WISCONSIN STATE BOARD OF FORESTRY,
Madison, Wisconsin.

GENTLEMEN: In accordance with your request I have made an investigation of the storage reservoirs of the Upper Wisconsin river, operated by the Wisconsin Valley Improvement company, and beg to submit the following preliminary report.

Yours truly,

C. B. STEWART.

STORAGE RESERVOIRS CONTROLLED BY THE WISCONSIN VALLEY IMPROVEMENT COMPANY.

Descriptive Data.

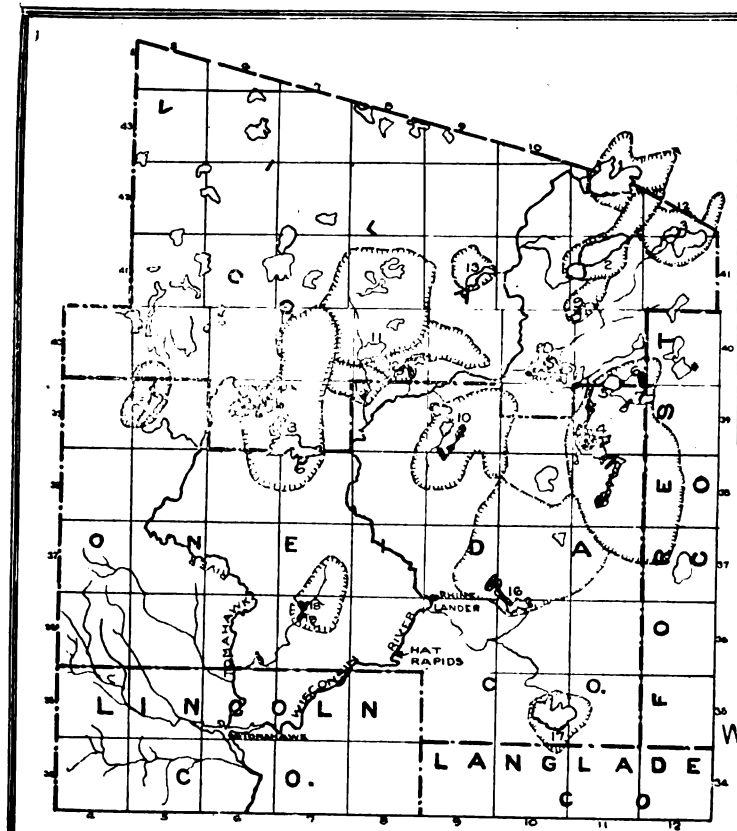
The source of the Wisconsin river is in numerous lakes in Vilas and Oneida counties in the northern part of Wisconsin. Plate I shows these counties and the main lakes and their tributary drainage areas in which the main branches at the headwaters of the river have their source. About nineteen of these natural lakes, having a total area of water surface of about 58 square miles, and a tributary drainage area of about 580 square miles as shown in the table, have been made into storage reservoirs by means of dams at the outlets of the lakes and are at present used by the Wisconsin Valley Improvement company for storage of flood waters and stream flow regulation.

In practically all cases, the lakes with the dams at their outlets have been used in the past either by river improvement companies or by individuals for storing water for purposes of floating logs down the streams. The river improvement companies were organized and operated under Chapter 86 of the General Laws of Wisconsin and Acts amendatory thereof, while individuals constructed their dams for improvement of navigation under special grants from the State Legislature. Section I of Chapter 335 of the Laws of Wisconsin for 1907 gave the Wisconsin Valley Improvement company the right to acquire the charters, rights of flowage and properties of these companies and individuals. In Appendix A to this report will be found a letter from Mr. G. D. Jones, Secretary of the Wisconsin Valley Improvement company, giving complete information as to the authority under which each of the several dams now controlled by this company was erected. A number of the larger lakes at present under control by the Wisconsin Valley Improvement company have been used mainly for storage purposes for stream flow regulation since about 1897.

Plates II-XI show the general character of the dams at the outlets of the lakes. The origial dams were constructed of logs and timber with sand filling. They were provided with either one or two timber sluices each about five feet to six feet in width and had suitable gates for controlling the rate of flow of the water. Five of these original dams, Twin Lakes, Long on Eagle, Lower Nine Mile, North Pelican and South Pelican have decayed and been replaced within the last three years by permanent concrete and iron structures. Two of these, Twin Lakes dam and Long on Eagle dam, have been equipped with tainter gates as shown on Plates II and IV. The Long on Eagle dam has been equipped, as required by law, with a marine railway or railway track extending over the dam from tailwater to headwater and provided with a suitable carriage having hydraulic power for its operation, so that launches up to fifty feet in length and five feet draft may pass from the Lower Eagle Chain of lakes to the Upper Eagle Chain of lakes or vice versa. This provides continuous navigation on a series of beautiful lakes, about thirty miles in length and having a water surface of about thirteen square miles.

A number of original dams that still remain have about reached the limit of their natural life and though serving their purpose they will probably be replaced by concrete structures in the near future. Practically all of the dams have been provided with suitable fishways which are kept open all of the time.

On the shores of the more attractive lakes many summer homes and summer resorts have been built. Table I, following, is an approximate estimate of the amount of money invested on the various lakes, under control by the Wisconsin Valley Improvement company for private homes and summer resorts, also the number of guests that can be accommodated and number of gasoline launches.



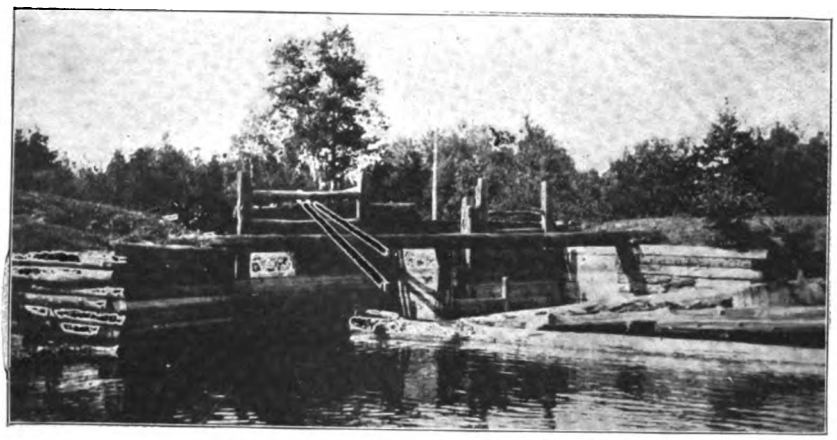
Reservoir		Location		Location of Dam			Areas in square miles		Capacity or storage million cu ft	
	Name	Township	Range	Section	Township	Range	Drainage	Reservoir	Summer	Winter
1	Meux des sert	42	11	17	42	11	8½	24	750	750
2	Twin	41-42	11	19	41	11	5 1/8	25	330	350
3	Long or Deerskin	41-42	12	7	41	12	4 3/8	23	370	460
4	" " Eagle	37-40	11-12	5	39	11	6 3/4	102	378	750
5	Lower 9 mile	39-40	11	4	39	11	2½	10	325	325
6	Upper 9 "	40	11-12	36	40	11	1/2	3	35	35
7	Seven mile	39	11-12	11	39	11	1	5	135	135
8	Minocqua	38-40	6-7	10	39	6	9½	79	330	840
9	Little Deerskin	40-41	10-11	33	41	11	1/2	8	28	28
10	Sugar Camp	38-39	8-10	17	39	9	3¼	50	500	500
11	Big St Germain	40-41	7-8	30	40	8	2½	64	210	210
12	Little St Germain	40	8-9	35	40	8	1½	20	95	95
13	Buckatabon	41	9	24	41	9	1¼	10	110	110
14	Pickerel	39-40	7-8	18	39	8	1/2	11	30	30
15	Squirrel Lake	39	5	30	39	5	2	17	120	135
16	North Pelican	36-39	9-11	4	36	10	2¼	89	0	135
17	South Pelican	35	10-11	11	35	10	3½	18	0	230
18	Rice Lake	36-37	7	6	36	7	1/2	12	40	40
19	Hancock Lake	36	7	15	36	7	5/8	6	30	30
					Totals		58¾	578	3839	5241

MAP
SHOWING
RESERVOIRS
OPERATED BY
WISCONSIN VALLEY IMPROVEMENT CO.
SEPT.-1910

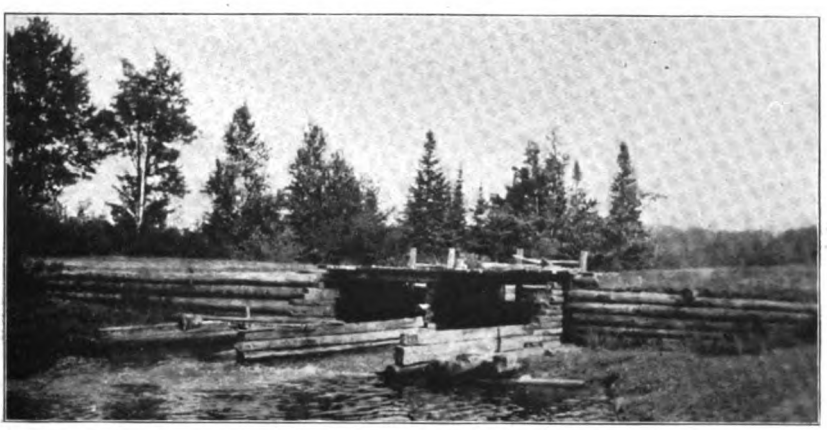
☐ Represents drainage area.

COMPILED FROM DATA OF WIS. VAL. IMP. CO.
C.B. Stewart Consult. Eng'r
Madison Wis.

PLATE I.



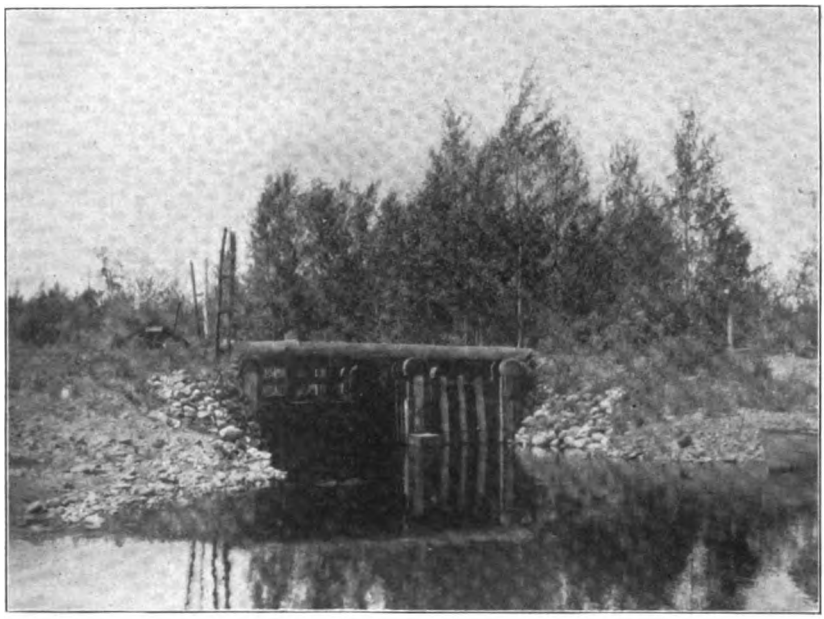
Lake Vieux Desert. View from Upstream.



Lake Vieux Desert. View from Downstream.

Twin Lakes. View from Downstream.

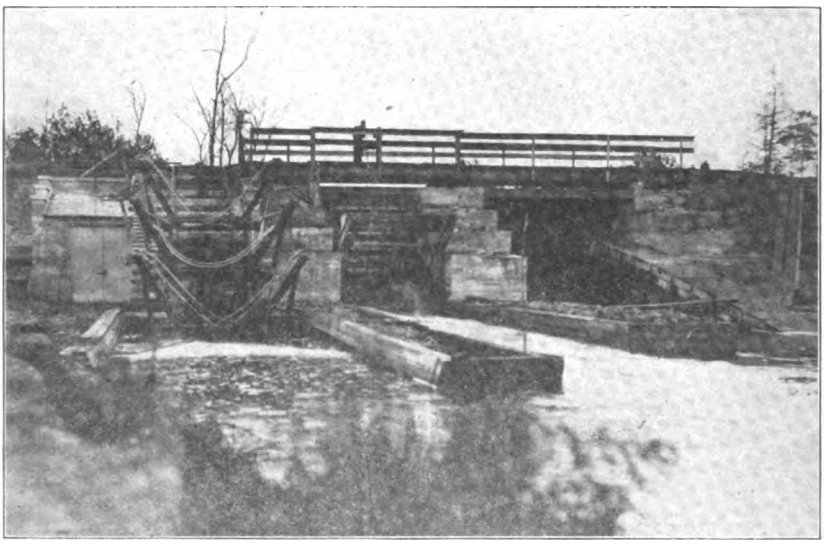
PLATE II.—LAKE VIEUX DESERT AND TWIN LAKES.



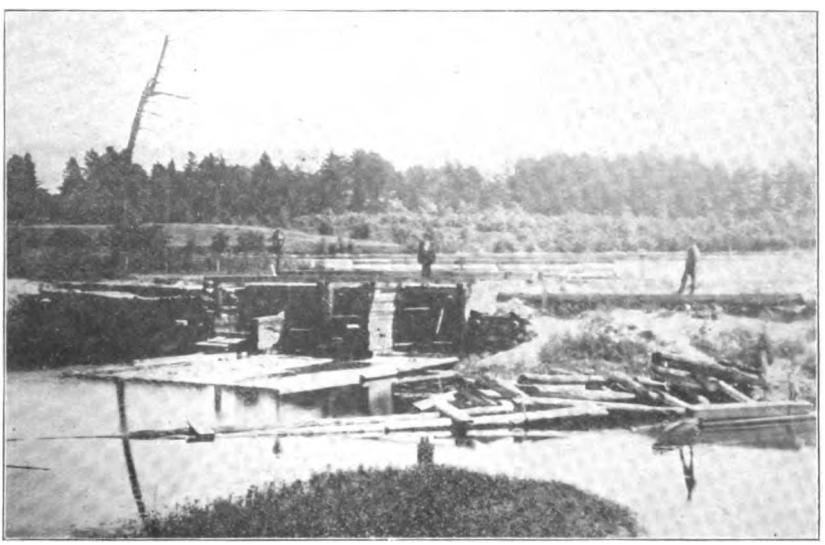
View from Upstream.

View from Downstream.

PLATE III.—LONG LAKE ON DEERSKIN RIVER.

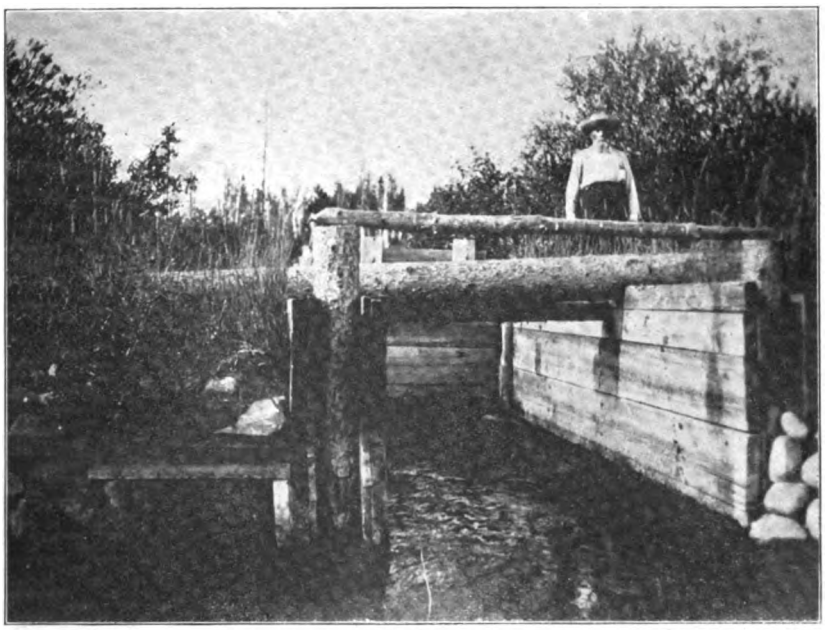


Long Lake on Eagle River. View from Downstream.



Minocqua Lake. View from Downstream.

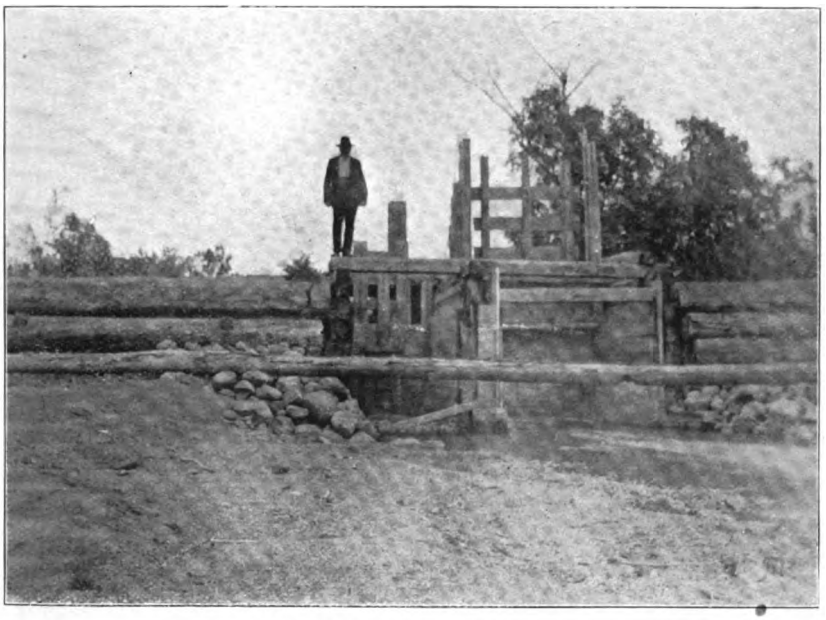
PLATE IV.—MINOCQUA LAKE AND LONG LAKE ON EAGLE RIVER.



View from Upstream.

View from Downstream.

PLATE V.—LITTLE DEERSKIN LAKE.



View from Upstream.

View from Downstream.

PLATE VI.—SUGAR CAMP DAM.

View from Upstream.

View from Downstream.

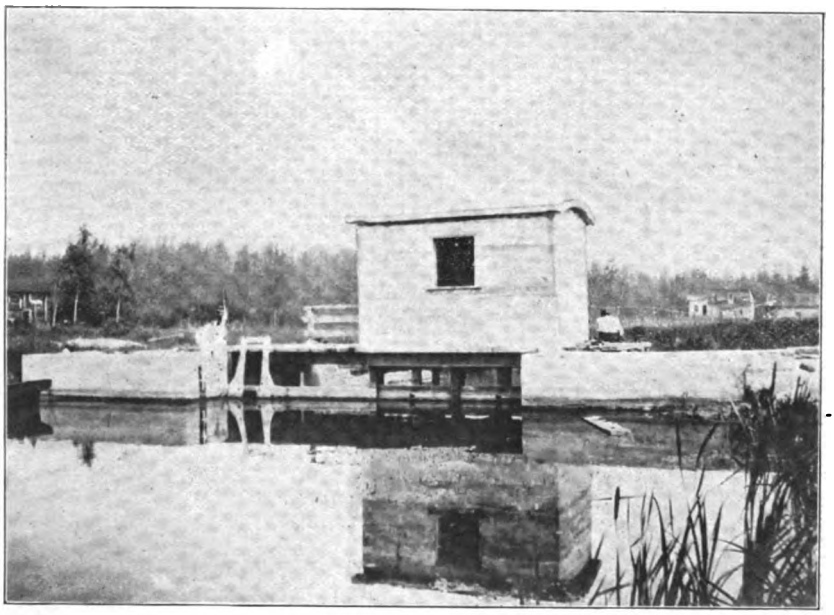
PLATE VII.—LAKE BUCKATAHPON

PLATE VIII.—SQUIRREL LAKE.

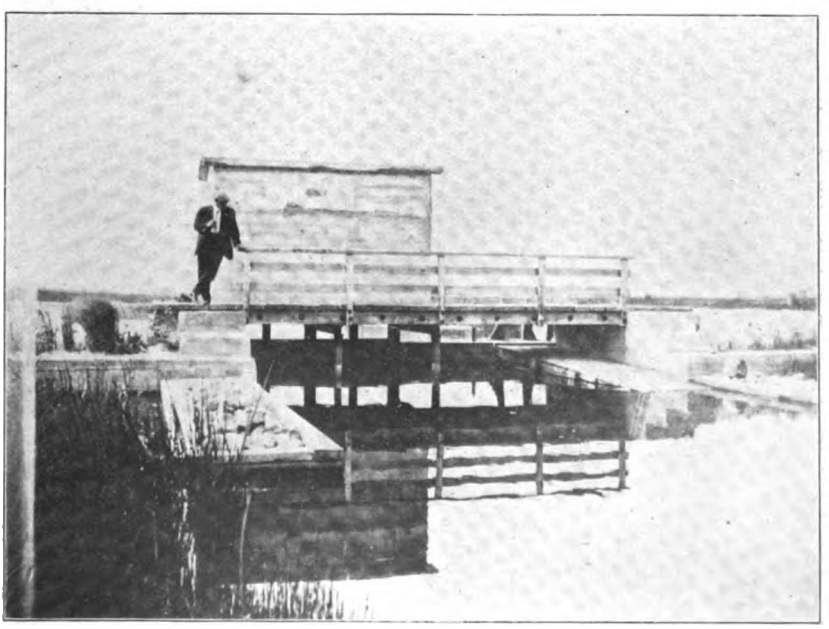
View from Upstream.

View from Downstream.

PLATE IX.—NORTH PELICAN LAKE.

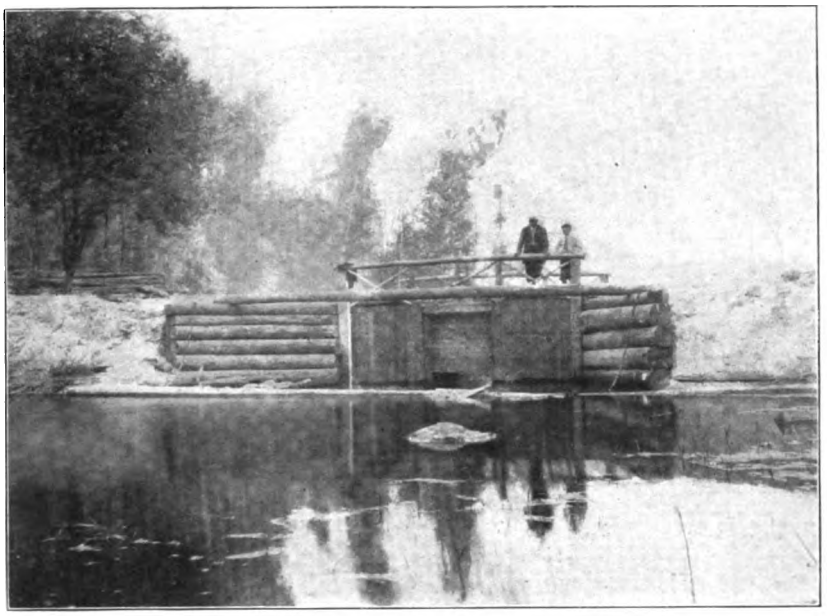


View from Upstream.

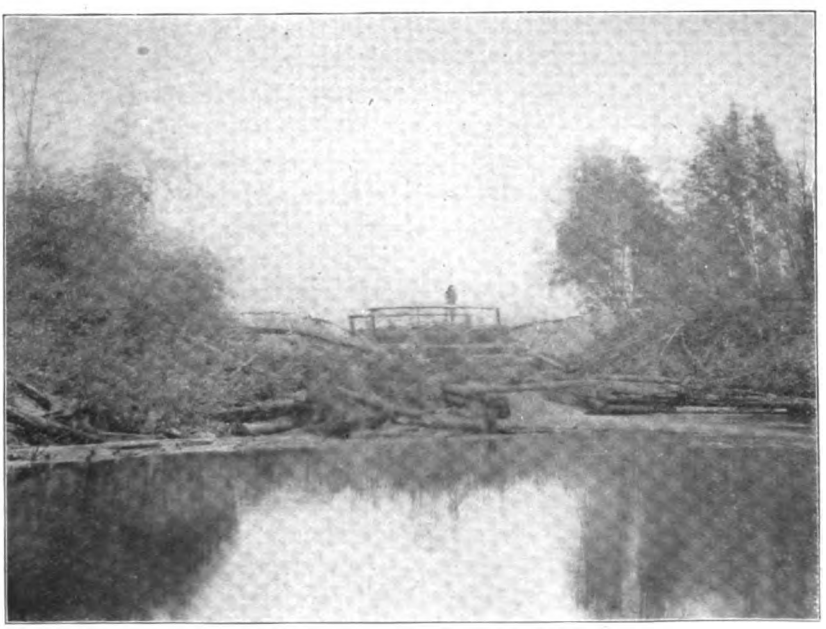


View from Downstream.

PLATE X—SOUTH PELICAN LAKE.



View from Upstream.



View from Downstream.

PLATE XI.—RICE LAKE.

TABLE I.

Name of lake.	No. of private homes.	No. of resorts and clubs.	Guests accommodated in resorts and clubs.	No. of gasoline launches.	Investment in buildings.
Vieux Desert	8	2	40	2	$11,000
Twin Lakes	2	2	180	16	18,500
Long on Deerskin	.....	2	60	7	16,000
Long on Eagle	40	7	125	80	42,000
Minocqua	40	8	270	150	125,000
Sugar Camp	.....	1	15	.....	2,500
Big St. Germain	2	3	85	1	14,000
Little St. Germain	.....	3	30	.....	6,000
Buckatabpon	.....	1	15	.....	2,000
Squirrel	1	1	35	2	9,000
N. Pelican	2	1	45	1	14,000
S. Pelican	36	2	110	30	35,000
Totals	126	33	960	289	$295,000

The total number of private homes, clubs and resorts is seen to be about 160, the number of guests which can be accommodated about 1,000 and the money invested in buildings about $300,000. In July, 1910, the resorts were about one-fourth filled, the absence of guests in most cases being considered to be due to the scare from fire. In one case only, namely Big St. Germain lake, was the cause ascribed to low water conditions.

OPERATION OF RESERVOIRS.

Section 2 of Chapter 335 of the Laws of Wisconsin of 1907 provides that it shall be the duty of the Wisconsin Valley Improvement company to manage, operate and maintain all of its reservoirs so as to produce as nearly a uniform flow of water as possible in the Wisconsin and Tomahawk rivers through all seasons by holding back and storing up in said reservoirs the surplus water in times of great supply and discharging the same in times of drought and a scarcity of water; also that during the times when it may be found to be impracticable to maintain at the same time such uniform flow in the river, both below the north line of

Lincoln county and above the same, the portions of said streams above said line shall be given preference.

The operation throughout the year is about as follows: In the spring of the year as soon as the natural flow of the river below the reservoirs is sufficient to supply the need of the power plants nearest the headwaters, the gates at the outlets of the lakes are closed and water collected. When the summer drought begins the gates are slightly opened and the stored water used to increase the flow in the river. During the fall of the year the natural flow of the river again increases as a result of the fall rains, and the gates are closed and the reservoirs partially refilled. This stored water, and any remaining from the summer period, is then gradually used during the late fall months and winter, the longer period of drought when the precipitation is slight and being stored in the form of snow.

In order to obtain the use of some of the lakes for storage purposes where summer homes and summer resorts have been built, it has been necessary to limit the range of fluctuation of lake level during certain months of the summer season. The high and low water limits of lake level and the months constituting the summer season have in some cases been stipulated by legislative act, as in the case of Long Lake on Eagle; and in other cases as North Pelican and South Pelican, they have been fixed by private contracts (See Appendix B and Appendix C). In the case of Minocqua lake they have been fixed by court rulings. When there are no special limitations to the high and low water lake levels during the summer the term *summer season* is considered as beginning with the spring rains and ending with the beginning of the fall rains. The balance of the year is termed the *winter season.* Table II gives the high and low water limits, for the winter and summer seasons, for the various lakes and also the months constituting the summer season, when specified. On some of the lakes changes are proposed in the matter of high and low water limits and summer season and these will be considered later.

Plates XII–XIX show the results of regulation of the various lakes, the high and low water limits, present and proposed, and also the rainfall conditions. A man is stationed at each of the principal dams and his duty consists of caring for and operating the gates of the dam and taking daily readings of the lake level, precipitation and temperature. The curves termed "rainfall deficiency" are the summations of the actual monthly variations in rainfall from the fourteen year monthly averages, starting with January first of each year. Referring to Long

TABLE II

PRESENT AND PROPOSED HIGH AND LOW WATER LIMITS ON STORAGE RESERVOIRS OPERATED BY THE WIS. VAL. I, MP. CO.

— Sept. 1910 —

	Reservoir	Winter Season			Summer Season			Remarks
		Low water App. gage read	High water	High water mark Old Log. Co's	Low water	High water	Time of year	
1	Vieux désert.	N.R. about -0-2	2'-2"	4'-0"	N.R. about -0-2	2'-2"		
	Proposed	N.R. about -0-2	3'-0"		N.R. about -0-2	3'-0"		High water Mon. prop.
2	Twin Lakes	N.R. +0'-3"	2'-8"	4'-0"	N.R. about +0-3	2'-8"		
	Proposed	Min. +0'-4"	2'-10"		Min. +0'-8"	2'-10"	June 1 - Oct. 1	High water mon. prop. Summer L.W. mon. prop.
3	Long on DeersKin	N.R. about +0-3	3'-2	4'-2"	N.R. about +0-3	3'-2"		
	Proposed	N.R. about +0-3	4'-0"		Min. +1'-0"	4'-0"	June 1 - Oct. 1	High water mon. prop. Summer L.W. mon. prop.
4	Long on Eagle	N.R. about -2-0	2'-0"	1'-6"	Min. +0'-0"	2'-0"	May 1 - Nov. 1	High water mon. prop. Summer L.W. mon. prop.
5	Lower 9 mile	N.R.	6'-0"	7'-8"	N.R.	6'-0"		Gage = +1'-4" with lake empty
6	Upper 9 mile	N.R.	5'-9"	5'-9"	N.R.	5'-9"		Gage = +3'-0" with lake empty
7	Seven mile	N.R. about 0-0	4'-10"	4'-10"	N.R. about 0-0	4'-10"		
8	Minocqua	N.R. about -1-11	1'-3"	1'-3"	Min 0'-0"	1'-3"	June 1 - Oct. 1	High water mon. prop. Summer L.W. mon. prop.
9	Little DeersKin	N.R. about 0-0	2'-0"	2'-0"	N.R. about 0-0	2'-0"		
10	Sugar Camp	N.R. about +1-6	7'-0"	8'-0"	N.R. about +1-6	7'-0"	Gage about 400' downstream Gage read with gate closed	
11	Big St. Germain	N.R. about +0-6	3'-6"	4'-0"	N.R. about +0-6 N.R. 1910, +0'-2	3'-6"		
	Proposed	N.R. about +0-6	3'-6"		Min. +0'-6"	3'-6"	June 1 - Oct. 1	more data needed
12	Little St. Germain	N.R. about +0-9	3'-0"	4'-0"	N.R. gage about +0'-9"	3'-0"	Gage about 1000' downstream Gage read with gates closed	
13	BucKatahpon	N.R. about +0-6	3'-8"	5'-0"	N.R. about +0-6	3'-8"		
14	PicKerel	No gage reading						
15	Squirrel Lake	N.R. about +1-7	3'-10"	about 4'-8"	N.R. about +1-7	3'-10	Gage about 1000' downstream Gage read with gate closed	
	Proposed	N.R. about +1-7	4'-0"		Min. +1'-10"	4'-0"	June 1 - Oct. 1	High water mon. prop. Summer L.W. mon. prop.
16	North Pelican	N.R. about -1-2	1'-0"	2'-0"	Min. -0'-4"	0'-0"	June 1 - Sept. 15	more data needed
17	South Pelican	0'-0"	2'-0"	2'-0"	Const. +1-0	Const. +1-0	April 1 - Nov. 1	High water mon. prop. Low water mon. prop.
18	Rice Lake							
19	Hancock Lake							

Note: N.R. abbreviated for Natural Run.

Lake on Eagle, Plate XV, it may be seen that the legal requirements as to lake level during the summer season of 1910 were practically fulfilled. Referring to Minocqua lake, Plate XVI, it may be seen that the water during the summer season of 1910 was about 1'0" too low. In this case the anticipated spring storage did not materialize and despite the fact that the gates were kept closed from April first, the lake level could not be raised to the desired point. North Pelican lake, Plate XIX, was practically kept up to the requirements. South Pelican lake was about 6" to 8" too low and could not be raised to the desired level. In this case the lake level went down about eight inches during June, July and August with the gates closed.

Excepting on these four lakes there are as yet no restrictions to the low water limits of lake levels during the summer season. Franchise rights allow that these lakes with their outlets gradually be allowed to assume a condition of nature in the summer season with gates wide open. The duration of the drought occurring in the late fall and winter is greater than that of the summer so that in general it may be stated that a certain percentage of the total water stored during the spring months can advantageously be held over from the drought of the summer season and used during the drought of the winter season. As to whether this water could be carried over without material loss would depend on local conditions. The most favorable conditions would be as follows:

First, ample allowable range in fluctuation of lake level to hold the lake up to the desired level during the summer season and in addition to receive the run-off from fall rains on the tributary drainage area.

Second, reservoir area practically the same at all lake levels, so there would be little or no additional loss from evaporation due to maintaining a higher summer and fall lake level.

If these natural features are lacking and it is still desirable to hold up the level during the summer season for the summer resort interests, probably the best solution would be to limit the length of the summer season making it end about September 1st or September 15th. This would give an opportunity for drawing the water down quickly between September 1st and the beginning of the fall rains, which usually come during September, October or November (See operation of North Pelican lake, September, 1909, Plate XIX).

Experience with reservoirs in sand soils has shown that the real storage is somewhat (perhaps 15 to 25 per cent) greater than the apparent amount as measured in the lakes, on account of storage in the

soil by raising the ground water level. Should the method of drawing the water down rapidly in the fall be used, a portion of this ground storage water would not be available as the slope of the ground water level would change slowly. Data are lacking on which to base an estimate of the amount unavailable from this cause, but it would probably not exceed about ten per cent of the water held by ground storage.

The effect of regulation by gates in holding spring floods until a later period of the summer, is to shorten the summer period of low lake level and keep higher, at least to some extent, the low water that would occur under natural conditions.

The question of regulating and keeping up the lake levels during the summer season on lakes where the summer resort interests were suffering, has been carefully investigated during the recent summer season of 1910.

CONSIDERATION OF COMPLAINTS AND ADJUSTMENT OF HIGH AND LOW WATER LIMITS.

The average annual rainfall for the fifteen years, 1896–1910, has been about 30 inches. For the year 1910 the total rainfall has amounted to about 19 inches, the lowest during this period of fifteen years. The year of next lowest rainfall during the fifteen year period was 1907 with a total of 23.16″. The year of maximum rainfall during the fifteen year period was 1900 with a total of 41.0″. As a result of the small rainfall during 1910, the levels of the lakes, where they had been allowed to gradually assume a condition of nature, have been lowered considerably below normal low water and in some cases have caused complaint from summer resort interests. This condition of low lake levels would probably not recur more often than once in twenty years, but in order to avoid such contingency in the future, new low and high water limits in certain cases have practically been agreed upon by the parties directly interested. The low water limits are approximately the normal low water levels. It was found possible in the cases where the low water limits were raised, to raise also the high water limits slightly, so that the allowable range of fluctuation of lake level remained the same. In other cases the thoroughfares between the lakes were the cause of complaints and harmony has been brought about by raising the low water limits slightly and arranging for the dredging of the thoroughfares, the cost of dredging to be divided equally between the interested parties, the Wisconsin Valley Improvement company and the summer resort interests.

Each of the lakes was visited and where complaints had been made, conferences were held with all of the owners of the summer resorts and private homes. In most cases two conferences were held, the first with the representative of the Wisconsin Valley Improvement company absent, and the next about a month later, with the representative of the Wisconsin Valley Improvement company present, so as to talk over proposed co-operation between the company and the summer resort interests.

Referring to the high water limits, Table II, it should be noted that the present and proposed limits do not exceed the high water limits of the old logging companies. The franchise and charter rights of these old companies allowed sufficient storage to float or drive logs down the streams. The best evidence obtainable of the flowage rights on the lakes, therefore, would be from the old high water marks. These logging companies on some lakes (lakes having small drainage areas) stored water through two seasons, so that on these lakes the present and proposed high water marks are considerably below the old high water marks.

As a general principle each lake should, if possible, have sufficient storage capacity or allowable range of fluctuation of water levels, from low water of winter season to high water, to hold the flood waters of the spring months in an average year. Actual data of these fluctuations have been recorded during the past three years and furnish a good guide for dry years. For average and wet years the data are as yet incomplete. For these years existing high water marks have been used as indicating the desirable and probable maximum high water limits.

Lake Vieux Desert, Plate XII. The conditions for boating and landing at piers were satisfactory on this lake and there were no complaints. High water limits proposed, +3′0″ for both summer and winter seasons; low water, natural run, for both summer and winter seasons.

Twin Lakes, Plate XIII. Complaint of the Hackley-Phelps-Bonnell Lumber company. This company owns and operates a lumber mill at Hackley, Wisconsin, and has extensive land and timber holdings on Twin lakes, and also on Long and Sand lakes, located about three miles east of Twin lakes. They own practically all of the real estate and buildings in the town and also own and manage the one hotel and one general store. The town has a population of about four or five hundred made up almost entirely of employes of the company and their families. The town is, therefore, the result of the operations of the company for the specific purpose of cutting and disposing of its timber. The com-

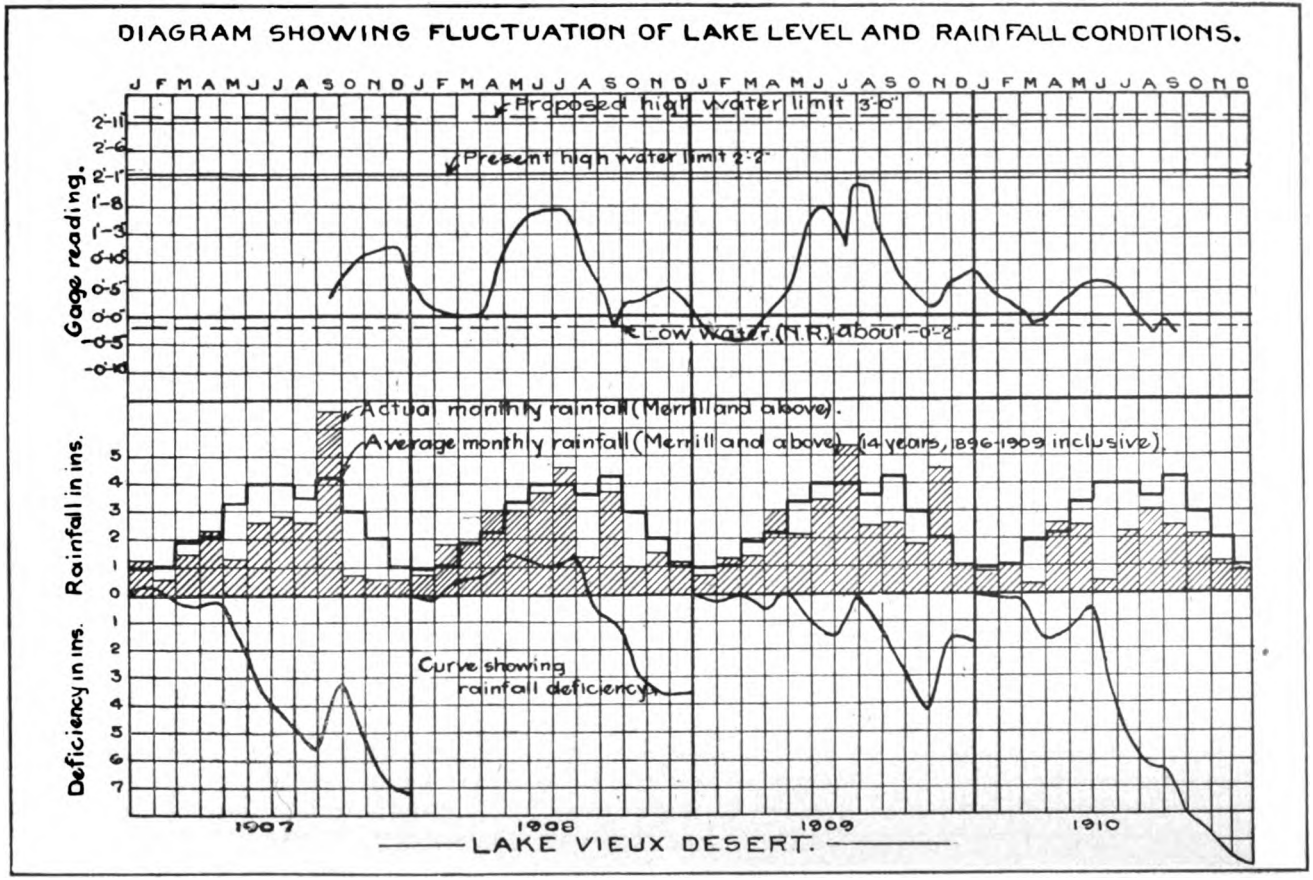


PLATE XII.

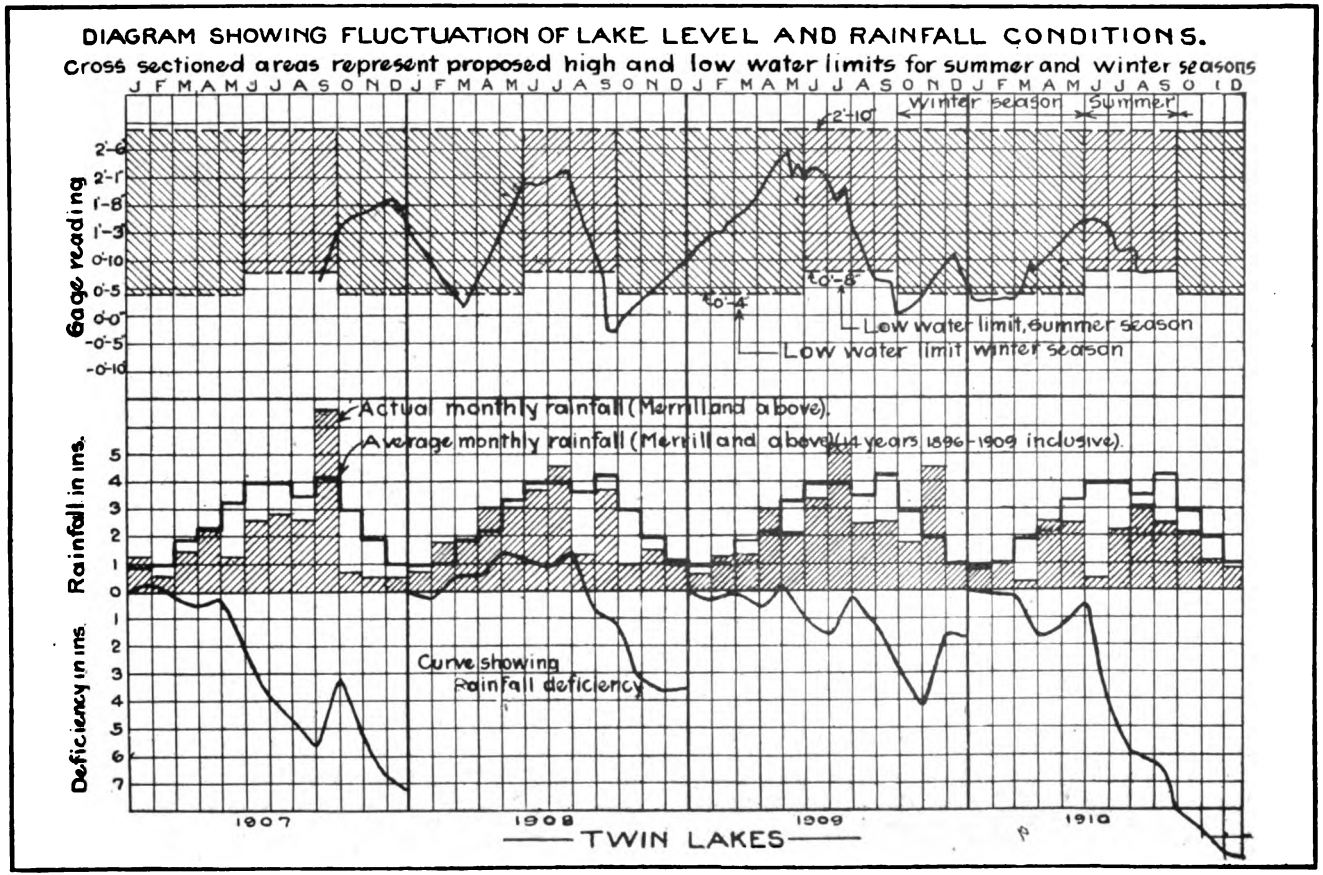


PLATE XIII.

pany brings logs from its various lumber camps on log trains, and rolls the logs from the cars into the water near a log hoist, by means of which they are carried into the mill, at an elevation of about thirty feet above the water. It is necessary to float the logs to and into this log hoist. The complaint of the lumber company is that when the water is allowed to go down in the summer and winter seasons, it becomes too low to float logs into the chute. A thorough examination was made of the physical conditions on August 4th, 1910, in company with a representative of the Lumber company and also of the Wisconsin Valley Improvement company. As the logs are being carried up the hoist they are sprayed with water, so as to remove all sand. Considerable bark is also removed by the handling. The result is that the sand and bark accumulate near the base of the hoist and have to be removed occasionally, so that the water will be of sufficient depth. This has been done in the past by means of a tug, using its propeller to wash the debris into the deeper surrounding water. At the time of the examination the reading of the guage at the dam at the outlet of the lake was +1′1″ and the depth of water at the base of the chute was about 2½ feet. Systematic soundings were taken on a line parallel to the shore, about 200 feet in each direction, and at the same distance as the chute from the shore, and showed that the original depth at the chute, must have been from eight to ten feet. A pike pole worked down into the sand, at the base of the chute showed that bark was mixed with the sand. The evidence showed conclusively that originally there was ample depth at the base of the chute for floating logs for all possible lake levels, and that restricting the low lake levels under present conditions would at most only be a temporary aid to the Lumber company. The solution of the problem, from the evidence, is really one of dredging and has no relation to the regulation of lake level. However, in order to promote harmony, it is proposed to limit the low water of the winter season to about the normal low water, or to gauge reading +0′4″; the low water of the summer season to be +0′8″ as determined from other conditions.

Complaint of Mr. Hanson, owner and manager of a summer resort on little Twin lake about four miles from Hackley. Mr. Hanson has about $4,000.00 invested in buildings and can accommodate about thirty guests. He has two gasoline launches for transfer of guests and baggage to and from Hackley. Little Twin lake is separated from Big Twin lake only by a sand bar through which there is a short thoroughfare about 50 feet in length. The thoroughfare is somewhat difficult to keep open, owing to its exposure to northeast winds the full length of

Big Twin lake. As a result the waves during storms wash sand into and partially fill the thoroughfare. The thoroughfare is a natural outlet from Big Twin lake, however, and the resulting current tends to keep it open, but not to a sufficient depth in times of low water to allow free passage of launches. Mr. Hanson's complaint was that he could not pass through the thoroughfare with launches, when the water was allowed to go down in the summer season. On August 6th, 1910, investigation showed a depth of water in the thoroughfare of about 2 feet with the gauge reading +1′1″ at the dam. The low water gauge readings, for conditions of natural run, in the summer seasons of 1908 and 1909 were –0′4″ and 0′0″ respectively. In the summer season of 1910 in accordance with a temporary agreement resulting from the present investigation, the water was not allowed to go below the gauge reading of +0′8″. The Wisconsin Valley Improvement company in times past has allowed Mr. Hanson at least part payment for services in cleaning the thoroughfare and during the season 1910 has allowed payment in full for such services. But this was not entirely satisfactory to Mr. Hanson. Restricting the low water in the summer time to moderate amounts as +0′8″ will not, however, entirely avoid the necessity of cleaning the thoroughfare. In order to provide permanent conditions it has been thought advisable to drive two rows of piles with sheet piling one on each side of the thoroughfare and extend the same into Big Twin lake to such a depth of water as would protect the thoroughfare from the wash of the waves. It is practically agreed between the interested parties, that following favorable action by the State Board of Forestry, the Wisconsin Valley Improvement company will perform this permanent work with the summer resort interests assisting by furnishing at least a portion of the ordinary labor.

High and low water limits proposed: High water, winter and summer seasons, +2′10″; low water, summer season, June 1—Oct. 1, +0′8″; low water, winter season, +0′4″.

Long Lake on Deerskin River, Plate XIV. Complaint of Sand Lake Fishing and Shooting club. Sand lake lies directly east of Long lake being connected thereto by a thoroughfare about one mile in length. The outlet of Sand lake is through this thoroughfare as shown by Plate I. The Fishing and Shooting club have an investment in buildings of about $10,000.00, with accommodations for about forty guests. They own considerable land on the east shore of Sand lake, with a continuous shore line of about two miles. The membership of the club is composed of residents of Illinois and Wisconsin, the majority being from Illinois. The club has owned this property for about twenty years.

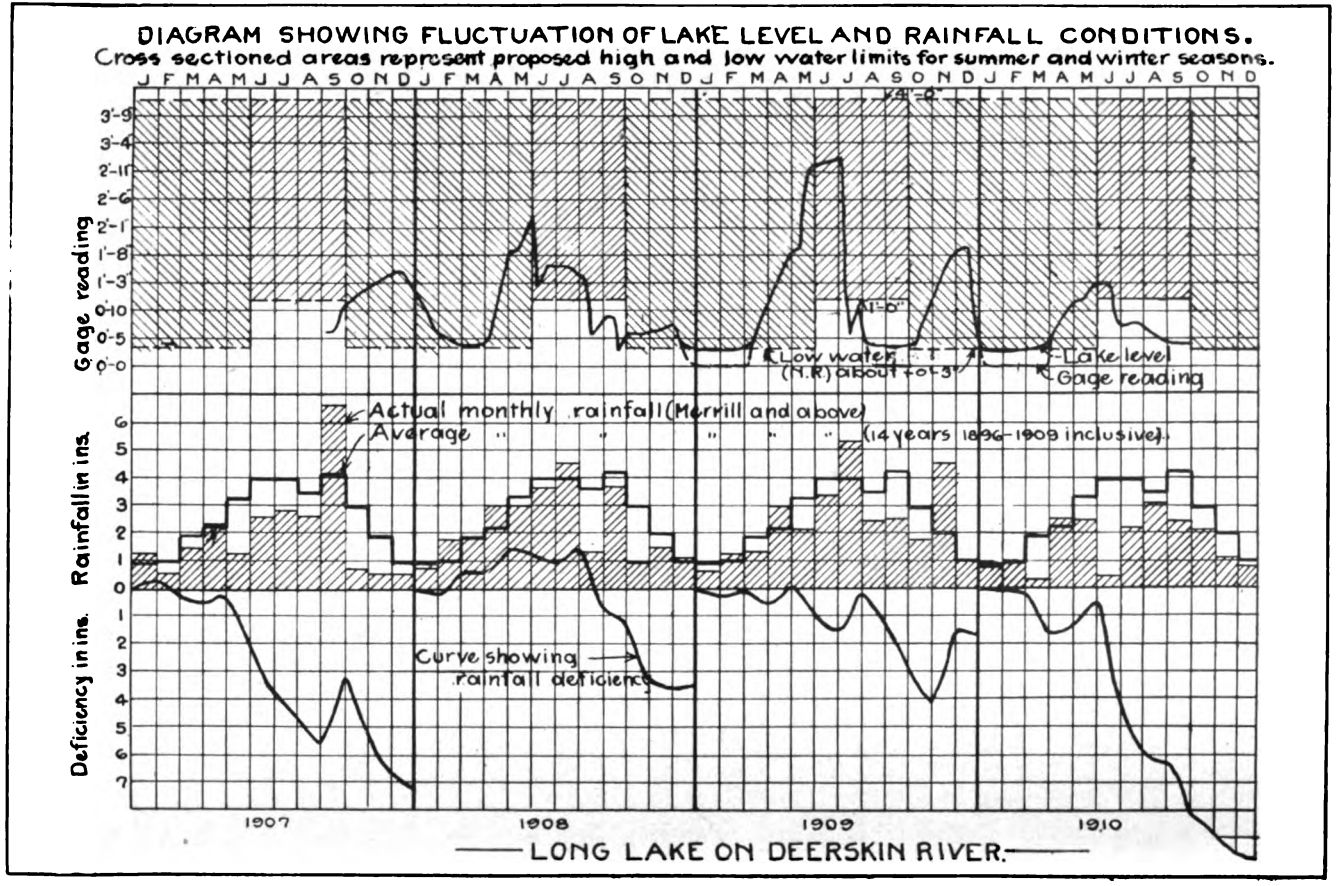


PLATE XIV.

The nearest railroad station is Hackley, about seven miles distant, and transportation of guests and members to and fro must be by water through the two lakes and thoroughfare. Wagon roads have been constructed from Hackley only as far as the west shore of Long lake. The beach where the club is located is sandy and the water of the lake shallow for several hundred feet from shore. The complaint of the club is that they cannot pass through the thoroughfare or get up to their landing pier with launches when the water is allowed to go down to a condition of natural flow in the summer season. Referring to the thoroughfare, the evidence from information from residents and guides, and from a study of the gauge readings for the past three years when compared with the depth in the thoroughfare, shows that for normal years the thorougfare in the past has been navigable by launches of two feet draft during the early months of the spring; then as the water was gradually allowed to go down to a condition of natural flow only rowboats could pass through. On August 6th, 1910, with the guage at the dam reading +0′7″, the minimum depth of water in the thoroughfare at each of three places was about eigth inches or about enough to float an ordinary rowboat containing two people. The average depth for the entire one mile of thoroughfare was about three feet. The average width was about twenty feet. The length of time required to row through the thoroughfare was about 45 minutes, the speed being slow on account of sharp bends. The distance in the thoroughfare where the depth would interfere with the passage of a launch of two feet draft, would not exceed about 150 feet. The soil at these places is sand mixed with stones and boulders. Some attempt at cleaning the thoroughfare had been made by the members of the club and by Mr. Hazen, who owns a resort on the west shore of Long lake. About four or five days' labor of one man would probably cover what had been done to date. After making a thorough investigation of the matter, the best solution and the one that would afford the most permanent relief seemed to be a combination of dredging the thoroughfare, and keeping up the low water level, during certain months of the summer. The matter was discusssed in conferences with the interested parties, Mr. H. P. Galpin, representing the Shooting and Fishing club, Mr. C. E. Hazen, owner of the resort on the west shore of Long lake, Mr. C. A. Phelps, representing the Hackley-Phelps-Bonnell company, who owned about 75% of all the land bordering Long and Sand lakes, Mr. A. A. Babcock, manager of the Wisconsin Valley Improvement company, and the writer. A willingness to co-operate was shown by all parties, and it was found that the fol-

lowing limits for water levels and arrangements as to dredging would be satisfactory to all: high water limit, winter and summer seasons, +4′0″; low water limit, summer season June 1—Oct. 1, +1′0″; low water, winter season, natural run, about +0′3″; an agreement between the interested parties, the Wisconsin Valley Improvement company and the summer resort interests, for equal co-operation in dredging and maintaining a thoroughfare between Long and Sand lakes during the summer season, June 1—Oct. 1, so as to have at all points a depth of at least 2′0″. This verbal agreement was to be subject to the approval of the Wisconsin State Board of Forestry and the Wisconsin Valley Improvement company.

Complaint of Sand Lake Shooting and Fishing club in regard to landing pier. The lake at the club house is very shallow with sand bottom so that to secure a landing place for launches it is necessary to extend their pier some distance into the lake. The pier used at present is about 100 feet long. In August, 1910, only row boats could land. In the early part of the summer, the club felt that the State should keep up the level of the lake during the summer so that launches could land at their pier. Later in the summer they concluded to extend their pier to a considerable depth of water and build a permanent boat house at the end, so this complaint was dropped.

Complaint of Mr. C. E. Hazen. Mr. Hazen owns a resort on the west shore of Long lake. He has about $6,000.00 invested in buildings and can accommodate about twenty-five guests. Mr. Hazen's only complaint was as to the thoroughfare between Long and Sand lakes, which has already been considered.

Long Lake on Eagle River, Plate XV. The water on this lake has been kept within legal limits during the summer seasons, 1907–1910, and there has been no complaint as to the water levels.

Complaint of Mr. J. B. Berry, member of the Three Lakes Rod and Gun club in regard to the marine railway. Section 1 of Chapter 335, Laws of 1907, provides that "The Wisconsin Valley Improvement company shall prior to June 1st, 1909, by such dam or dams and by locks, marine slides or other safe and convenient means, make and thereafter maintain the Eagle river between said Long and Cranberry lakes navigable for the safe and convenient passage of boats of all kinds and sizes up to and including boats 50 feet in length and 12 feet beam and drawing 5 feet of water. Said Wisconsin Valley Improvement company shall have the right to charge and collect reasonable and uniform tolls for the passage of boats through and over said works proportioned to the size of the boat, not, however, exceeding in the aggregate the

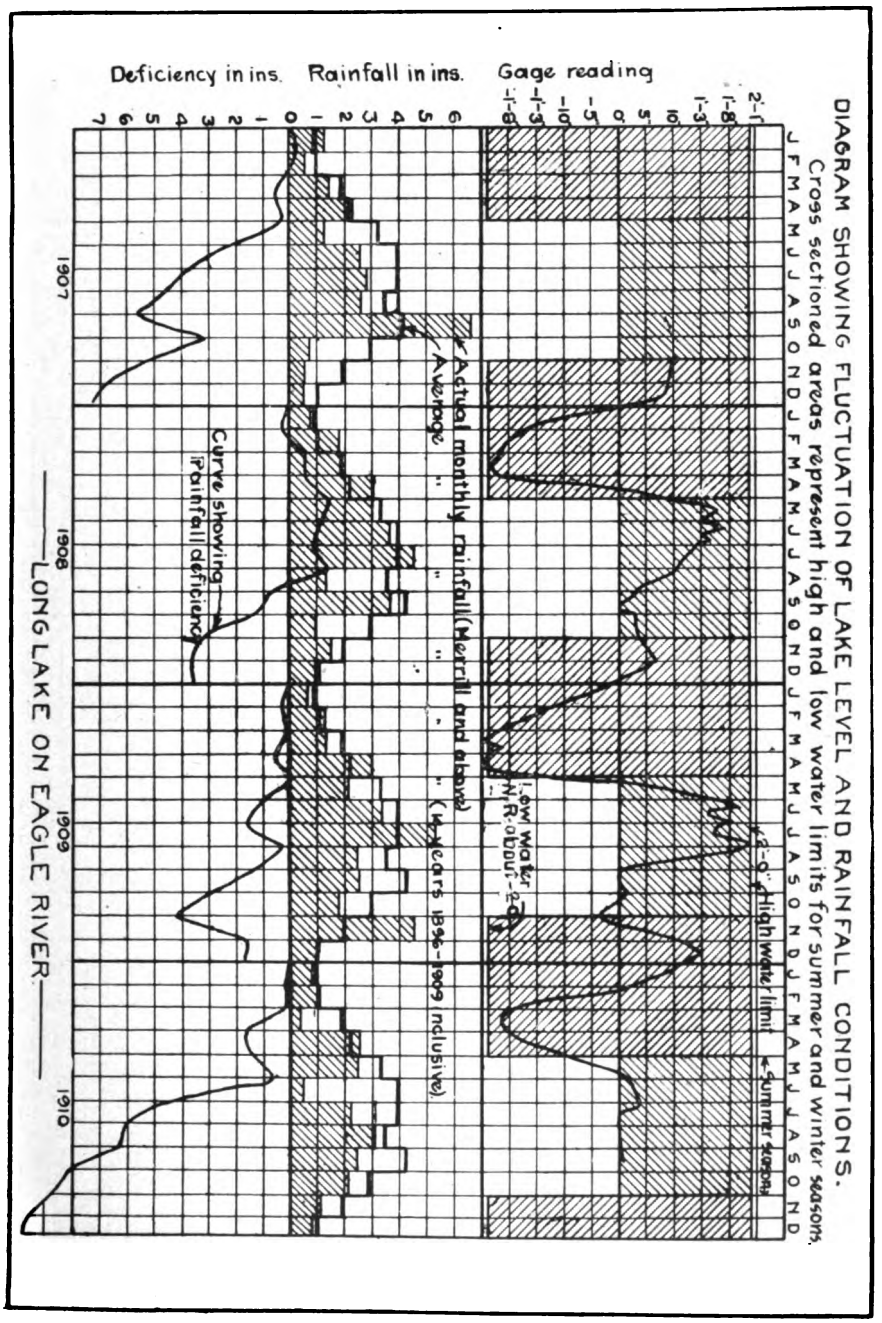


PLATE XV.

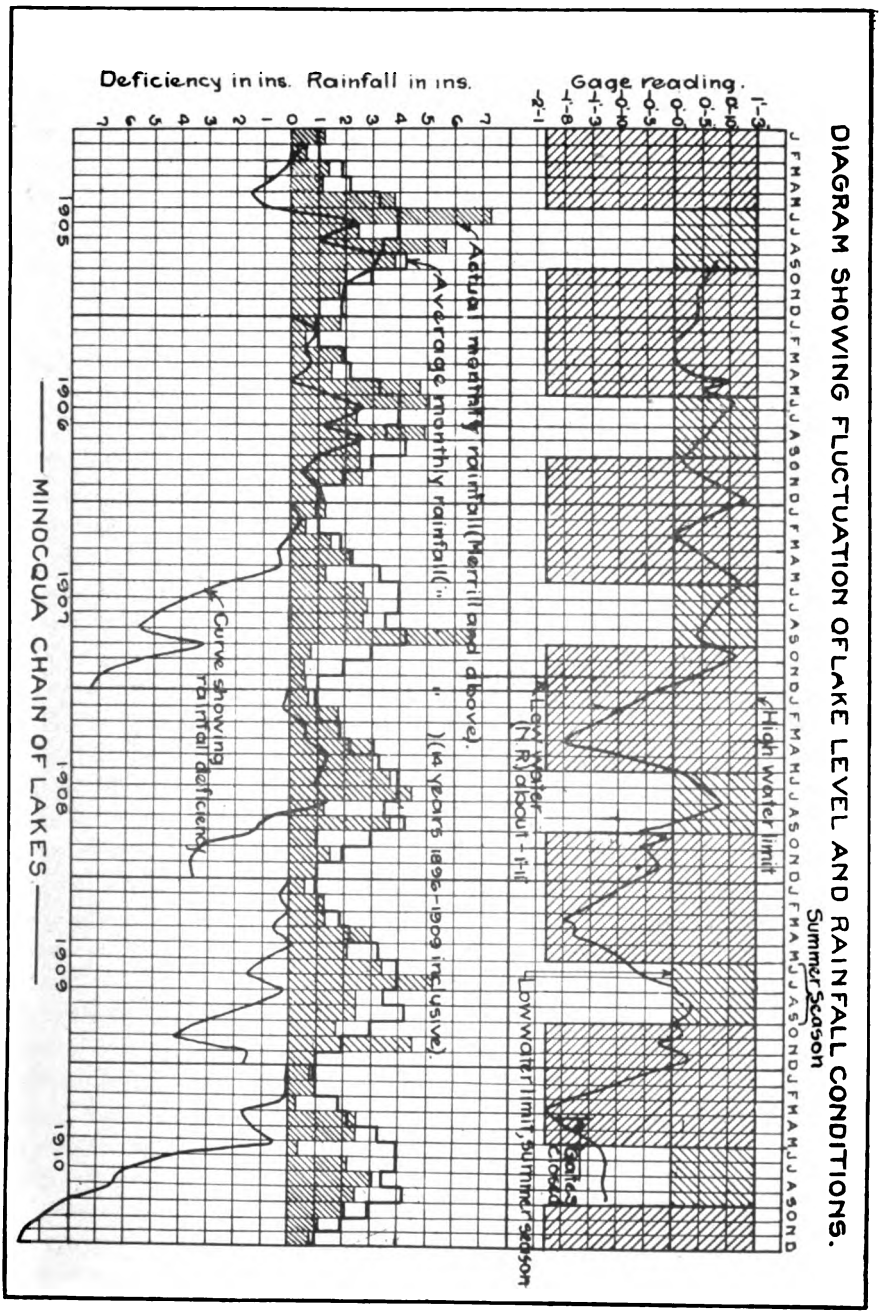


PLATE XVI.

actual cost of the care, maintenance and operation of said locks, marine slides or other means of passage.

Mr. Berry complained in August, 1910, because of the delay in completing this work, and feared the company was not acting in good faith. In August, 1910, at the time of the investigation, about 90% of the dredging in Eagle river below the dam had been completed and the marine railway was ready for operation except for the placing of the cable for the car. The hydraulic dredge was working at the time and having considerable trouble and interruption owing to interference from limbs of trees covered by sand in the bed of the stream. The work was continued during the summer and fall, and I am informed has now been completed and the railway will be ready for operation in the spring of 1911. The question of tolls to be charged has not as yet been adjusted.

Minocqua Lake, Plate XVI. The water on this lake in August, 1910, was about 1′0″ below the low water limit of the summer season. The gates had been kept closed since April 20th, so that the entire run-off of the spring months had been collected. All thoroughfares were navigable and landing piers accessible, and though higher water would have been preferred, the summer resort interests realized that the cause was due to a lack of rainfall and did not complain.

Big St. Germain Lake, Plate XVII. Complaints of Mr. Chaberson and Mr. McGregor. Both Mr. Chaberson and Mr. McGregor complained of the low water conditions in the summer months of 1910. Mr. Chaberson owns a resort on the east shore of the lake, has about $8,000.00 invested in buildings, and can accommodate about fifty guests. He owns about one-half mile of shore line, has about ten row boats but no launches. The lake at Mr. Chaberson's resort is quite shallow with sand bottom. The landing pier is about fifty feet long and at the time of the investigation, in July, 1910, the depth of the water at the end was about 8″. The reading of the guage at the dam at this time was +0′2″. During July, 1909, one year previous the gauge reading was +1′0″ During October, 1909, it was +0′9″. Then after the rains of November the gauge reading was +3′5″, or 1″ below high water mark. The drainage area of this lake is about 64 square miles and reservoir area about 2½ square miles. The observed data concerning lake levels extends over only two dry years, but it is evident from these that the storage capacity is insufficient for the spring months and barely sufficient for the fall months. Considerable flooding would result from raising the high water limit above 3′6″.

Mr. McGregor has abouf $3,000.00 invested in buildings and can ac-

commodate about twenty guests. He owns about one-half mile of shore line and has one launch. Conditions for landing of boats at Mr. McGregor's are more favorable than at Mr. Chaberson's.

Mr. J. Hunter owns a resort on this lake, has about $1,000.00 invested in buildings and can accommodate about fifteen guests. He owns about one-quarter mile of shore line. Conditions for landing of boats were favorable and no complaint was made.

Mr. Valley owns a private home on this lake, and has about $2,000.00 invested in buildings. Conditions are favorable for landing of boats. He preferred higher water during the summer season but made no special complaint.

Mr. F. Backus owns a private home on Lake Content which immediately adjoins Big St. Germain. He has about $20,000.00 invested in buildings. Lake Content has an area of about one-quarter square mile and the entire shore line is owned by Mr. Backus. Row boats pass from Big St. Germain into Lake Content but launches cannot enter. The water level of Lake Content in the summer season is kept up by a dam constructed by Mr. Backus. Mr. Backus owns considerable of the shore line on Big St. Germain and no complaint was made as to water conditions on that lake.

In order to prevent a recurrence of abnormally low water conditions on Big St. Germain, such as occurred during the summer of 1910, and until further data can be collected, it is advised that the following lake level limits be adopted. High water, summer and winter seasons, +3′6″; low water, summer season, June 1—Oct. 1, +0′6″; low water, winter season, natural run.

Squirrel Lake, Plate XVII. Complaints of Mr. Henry Hanson and Mr. C. S. Havener. Mr. Hanson owns a summer resort on the east shore of Squirrel lake, has about $6,000.00 invested in buildings and can accommodate about 35 guests. He owns about one-quarter mile of shore line and has one launch. Mr. Havener owns a summer home on the west shore of the lake, has about $3,000.00 invested in buildings and has one launch. Both Mr. Hanson and Mr. Havener complained of low water conditions during the summer of 1910. Favorable conditions for landing of launches exist at both places. On July 18, 1910, the reading of the gauge at the dam, with the gate closed, was +1′7″; in July and August, 1909, the reading averaged about +3′0″; in September and October, 1909, just before the fall rains, the reading was about +1′10″. The highest water during the two years' record has been +3′10″ in the spring of 1909. Well defined high water marks of the old logging companies exist for a reading of about +4′8″. The storage capacity is

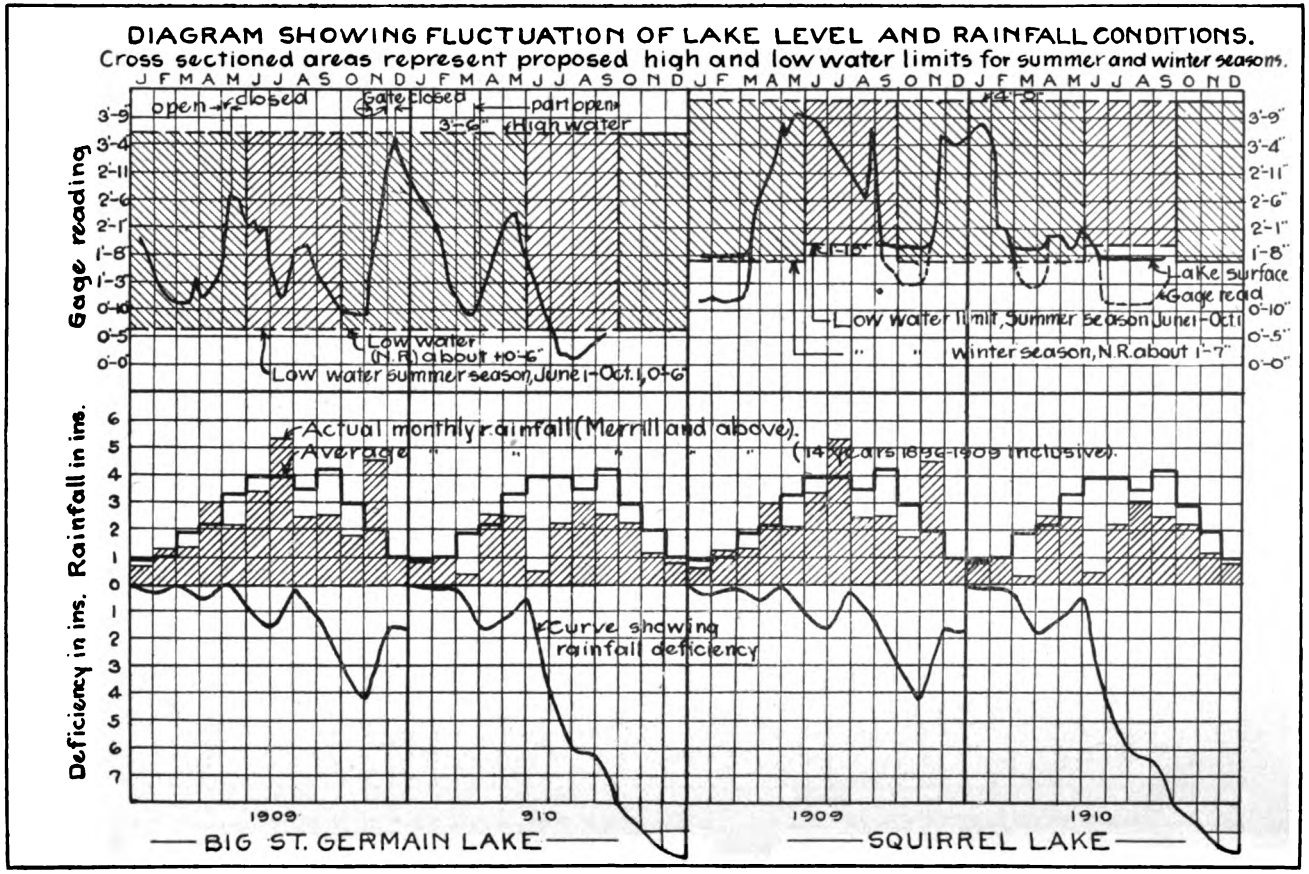


PLATE XVII.

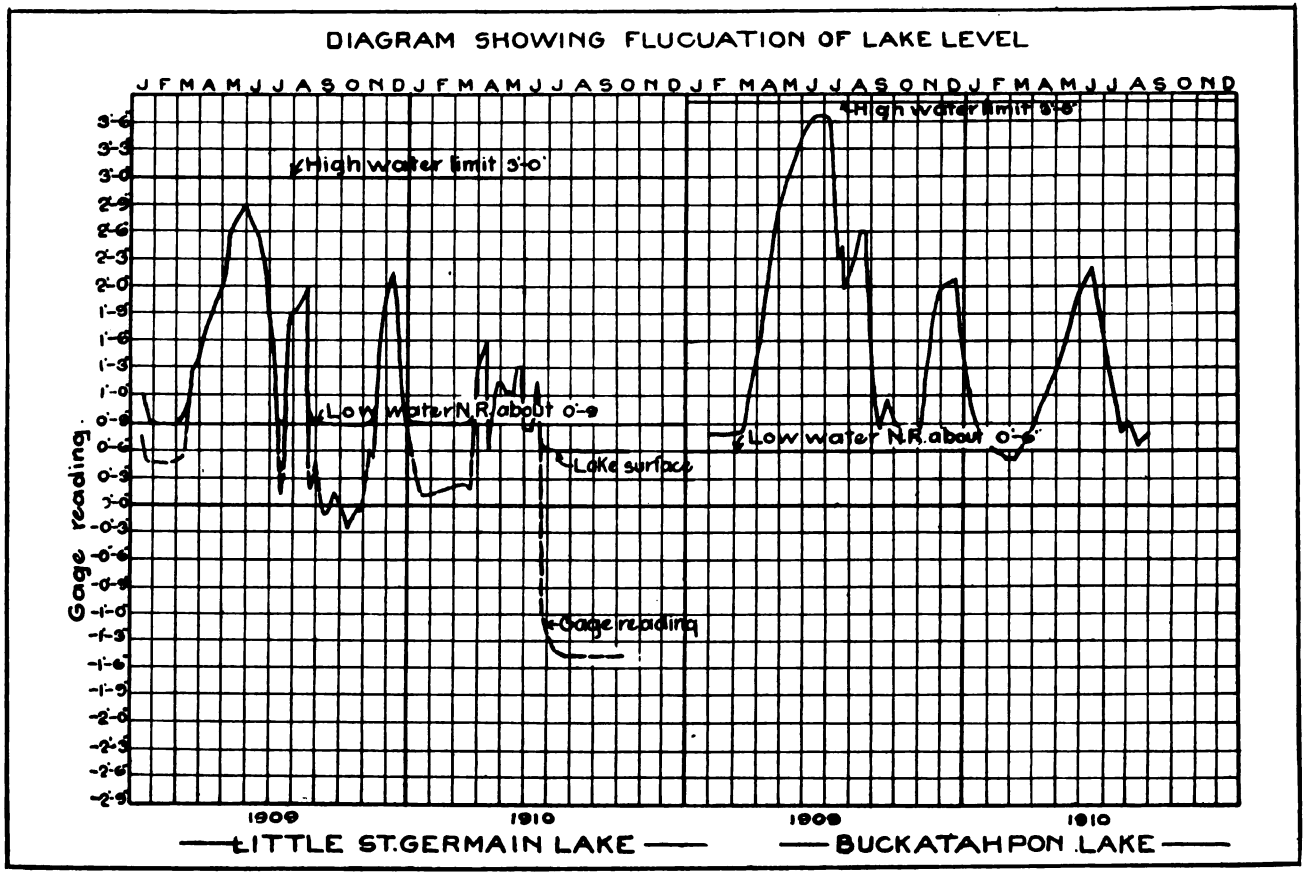


PLATE XVIII.

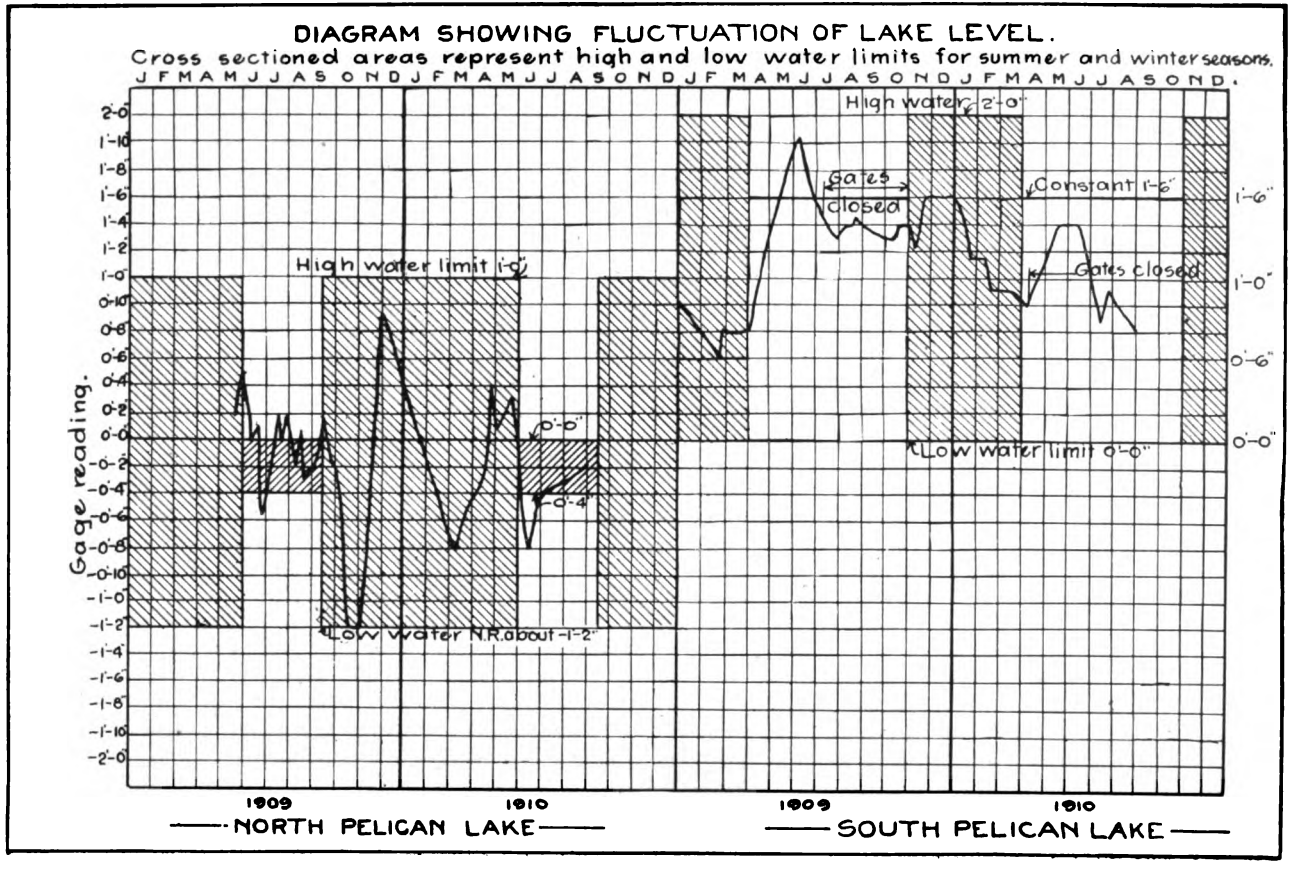


PLATE XIX.

insufficient for the spring rains and probably barely sufficient for the fall rains. The following limits for lake levels are proposed: high water, summer and winter seasons, +4′0″; low water, summer season, June 1—Oct. 1, +1′10″ with the gate closed; low water, winter season, natural run.

On July 18, 1910, a white paint mark was made on a large boulder located on the southwest shore of Bolger island, 3′0″ above the water level of that date. The proposed high water mark is 0′7″ below said mark, and the proposed low water mark for the summer season is 2′9″ below said mark.

North Pelican Lake, Plate XIX and Appendix B. The water levels on this lake have been kept practically within the limits called for by private contract and no complaints were made. The lake has a drainage area of about 89 square miles and a reservoir area of about 2¼ square miles. The observed data concerning lake levels extends over only about one and one-half years. The available storage capacity is insufficient for the spring months and barely sufficient for the fall months. The summer season ends September 15th and usually gives an opportunity to draw the lake down before the fall rains. It is advised that the limits of lake levels be left the same as agreed by private contract.

South Pelican Lake, Plate XIX and Appendix C. The water on this lake on July 20, 1910, was 8″, below the level called for by private contract. The gates had been closed since April 20th, so that the entire run-off of the spring months had been collected. All landing piers were accessible and conditions for navigation still favorable. It is advised that the limits for lake levels be left the same as agreed by private contract.

RELATION OF STORAGE RESERVOIRS TO STREAM FLOW.

CHARACTER OF SOIL AND TOPOGRAPHY.

In order to intelligently study the question of storage reservoirs already in use or proposed and of the benefits resulting from increased uniformity of stream flow, it has been necessary to investigate the subject of stream flow of the upper Wisconsin river in considerable detail. Referring to the river as a whole it would be well to state that the total fall developed and utilized by water power plants at the present time amounts to about 300′, while a future development of about an equal amount can be counted on with reasonable certainty.

The portion of the watershed of the Wisconsin river considered is at and above Merrill and located in Vilas, Oneida and Lincoln counties. The soil of these counties consists of glacial drift of porous sandy material, varying from pure sand in some places to sand mixed with a slight amount of clay in others. The counties of Vilas and Oneida lie entirely within the Late Wisconsin Drift formation, the most recent and probably most extensive of the glacial deposits in North America. One of the smaller lobes from the great ice sheet was forced down the valley of the Wisconsin and extended into Lincoln county. The terminal moraine, from three to ten miles wide [1] crosses the Wisconsin river about six miles above Merrill. From this point one arm extends northwesterly and the other northeasterly, the latter lying just north of and parallel to the Prairie river. The glacial formation lying just south of the Late Wisconsin has recently been termed by geologists the Third Drift formation of the Early Wisconsin. The soil of this formation is quite similar to that of the Late Wisconsin, except that it has slightly more clay and gravel. The Prairie river emptying into the Wisconsin river just above Merrill lies almost entirely in this formation. Excepting for this one river with a watershed of about 120 square miles, the entire

[1] See Bulletin No. XVI of the Wisconsin Geological and Natural History Survey; "Geology of North Central Wisconsin," by Samuel Weidman.

watershed of the Wisconsin river considered lies in the Late Wisconsin Drift formation. The land is more or less rolling but the slopes are gradual with the variations in elevation not exceeding about 100 feet. The most characteristic feature of the topography, especially of Vilas and Oneida counties, is the sand hills with rounded tops, interspersed with circular or elongated valleys, and occupied by lakes with or without outlets. The lakes evidently feed the rivers by underground flow and thus form storage reservoirs. In cases where the lake surface occupies a large part of the tributary drainage area, their usefulness as storage reservoirs is doubtful as evaporation from the lake surface would cause a large draft on the surrounding ground storage. This question is treated later in connection with the yield of watersheds with various percentages of water surface.

Excepting about three or four per cent of the land, which has been cleared, the land consists almost entirely of cut-over land with second growth timber, about one-half of the land having been burned over in the last two or three years.

RAINFALL AND RUN-OFF DATA.

The character of the soil and topography, together with absence of any erosion indicates that surface flow from rains will not occur except during periods of the early spring when the ground is frozen. Fortunately the distribution of rainfall throughout the year is such that the heavy rains occur during the summer and fall months, so that the injurious results of surface flow are greatly reduced. The average monthly precipitation in inches on the watershed of the Wisconsin river above Merrill, for the fourteen years, 1896–1909, has been as follows:

January	0.89	July	3.91
February	1.00	August	3.42
March	1.82	September	4.20
April	2.15	October	2.94
May	3.25	November	1.89
June	3.95	December	1.01
		Total	30.48

In investigations of rainfall and run-off it is convenient and customary to use what is termed the water year, beginning with December and ending with the following November, and to divide this into periods as follows:

The "Storage" period includes the months from December to May inclusive. During the first half of this period, December, January and

February, the precipitation is usually stored in the form of snow. During this time stream flow is almost entirely maintained from ground water storage. In the second half, March, April and May, the water from the melting of the snow and spring rains, in part runs off by surface flow and in part enters the soil, and is temporarily stored by a general raising of the ground water level. During this time the evaporation is slight, demands of plant life are at a minimum, and stream flow increases very rapidly.

The "Growing" period includes the months of June, July and August, and is the period when vegetation is most active. Evaporation from soil and water and absorption by plant life are at a maximum. Ordinary rains during this period when not of sufficient magnitude or duration to wet the soil to the ground water level are either lost by evaporation or absorbed by plant life. Heavy rains, however, as shown, frequently occur and add to the amount of ground water storage.

The "Replenishing" period includes the months of September, October and November. During this period the demands of vegetation have diminished and evaporation much decreased, so that with moderate rains a portion of the water enters the soil and raises the ground water level. The amount and distribution of the rains during this period are the main elements which determine the magnitude of stream flow during the drought of December, January and February.

Table III following, gives the monthly precipitation in inches on the watershed of the Wisconsin river above Merrill, for the years 1896–1910. The data are from daily observations at about ten stations distributed over the watershed and were compiled by Mr. A. A. Babcock from the records of the U. S. Weather Bureau and Wisconsin Valley Improvement company. From 1896–1907 inclusive the stations were Antigo, Crandon, North Crandon, Heafford Junction, Merrill, Koepenick, Tomahawk, and Minocqua; from 1908–1910 the stations were Antigo, Crandon, Merrill, Koepenick, Minocqua, Vieux Desert, Long Lake, Deerskin Dam, Twin Lakes, Big. St. Germain, Sugar Camp Dam, Prentice and Rhinelander.

TABLE III

AVERAGE RAINFALL IN INCHES

ON THE

WATERSHED OF THE UPPER WISCONSIN RIVER

MERRILL AND ABOVE.

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1896	0.95	0.41	1.03	3.06	4.72	1.83	3.04	4.13	2.17	2.88	4.11	1.20	29.53
1897	1.40	1.36	2.21	1.11	2.07	4.92	3.18	1.70	2.50	2.98	1.31	0.56	25.30
1898	0.65	1.80	1.60	1.70	2.49	4.01	2.67	1.33	2.47	2.82	1.94	0.29	23.77
1899	0.89	0.86	2.38	3.33	3.98	3.79	2.20	3.25	3.20	4.78	0.42	1.79	30.87
1900	0.61	1.30	1.44	2.55	1.42	2.68	8.40	4.96	8.23	7.58	1.03	0.80	41.00
1901	0.80	0.77	3.90	0.65	1.77	4.28	6.79	3.47	4.59	2.28	1.45	0.61	31.36
1902	0.88	0.87	0.87	2.48	2.74	4.30	2.14	1.51	1.89	2.19	4.24	1.19	25.18
1903	0.48	0.54	2.45	2.27	5.49	1.65	5.47	6.39	7.56	2.38	0.86	0.59	36.13
1904	0.40	1.94	1.62	2.08	5.86	5.78	3.54	4.36	7.05	5.43	0.29	2.45	40.20
1905	1.21	0.65	1.38	1.15	3.83	7.32	2.45	5.65	3.86	2.02	1.75	1.06	32.33
1906	1.85	0.54	2.00	1.49	4.76	5.07	2.59	4.91	2.47	2.45	2.60	1.10	31.63
1907	1.24	0.54	1.45	2.25	1.23	2.61	2.81	2.61	6.65	0.73	0.52	0.52	23.16
1908	0.65	1.73	1.85	3.04	2.00	3.66	4.46	1.28	3.66	0.94	1.47	1.09	26.89
1909	0.53	1.26	1.29	2.95	2.11	3.36	5.26	2.41	2.45	1.71	4.48	0.93	28.74
1910	0.76	0.97	0.29	2.46	2.42	0.38	2.13	3.06	2.40	2.12	1.12	0.83	18.94
Average 1896-1909	0.89	1.00	1.82	2.15	3.25	3.95	3.91	3.42	4.20	2.94	1.89	1.01	30.43
Average 1896-1910	0.88	1.00	1.72	2.17	3.19	3.71	3.79	3.40	4.08	2.88	1.84	1.00	29.66

DISTRIBUTION OF RAINFALL IN VARIOUS PERIODS FROM 15 YEAR AVERAGES, 1896–1910.

Months	Period	Rainfall in inches		Percentage of total	
Dec.-Jan.-Feb.	First half Storage	2.88		9.7	
Mar.-Apr.-May	Second half "	7.08		23.9	
	Total "		9.96		33.6
June-July-Aug.	Growing		10.90		36.8
Sept-Oct.-Nov.	Replenishing		8.80		29.6
	Total		29.66		100.0

Note:- Rainfall data from the records of the Wis Valley Imp. Co.

TABLE IV

AVERAGE RAINFALL IN INCHES

ON THE

WATERSHED OF THE UPPER WISCONSIN RIVER

BETWEEN HAT RAPIDS AND MERRILL

Year	Jan	Feb	March	April	May	June	July	Aug	Sept.	Oct.	Nov.	Dec.	Total
1905												1.22	
1906	2.56	0.53	2.17	1.47	4.34	5.62	2.74	5.64	2.78	2.97	2.42	1.45	34.69
1907	1.42	0.55	1.74	2.21	1.78	2.78	2.66	2.68	6.08	0.87	0.69	0.42	23.88
1908	0.67	1.53	1.89	2.93	3.44	3.96	4.73	1.55	3.38	1.10	2.00	1.10	28.22
1909	0.65	1.26	1.28	3.04	2.21	2.47	3.96	2.42	2.79	1.33	4.69	1.14	27.24
1910	0.72	0.82	0.30	2.86	2.26	0.88	1.97	3.23	2.53	2.16	1.39	0.66	19.50
Average	1.20	0.94	1.46	2.50	2.81	3.08	3.21	3.11	3.51	1.69	2.24	0.95	26.71

Note:- Above values are averages of observations taken at Crandon, Koepenick, Merrill, Minocqua, Prentice and Rhinelander.

The complete rainfall data for the year 1910 were not available for this investigation, so averages for both fourteen years, 1896–1909, and fifteen years, 1896–1910, are given. The most noticeable features in the data are the high average rainfall and also extreme range in the rainfall during the summer months. The maximum monthly rainfall for the fifteen year period was 8.40″ in July, 1900. The minimum monthly rainfall was 0.38″ in June, 1910. The table also shows the distribution of the average rainfall to be about 3″ or 10% of the total in December, January and February; about 7″ or 24% in March, April and May; about 11″ or 37% in June, July, and August, and about 9″ or 30% in September, October and November.

In order to investigate the relation of rainfall to run-off under natural conditions free from the effects of storage reservoirs at present under operation, it has been necessary to consider a portion of the watershed and river between Hat Rapids and Merrill. On this watershed of about 1,530 square miles, which also includes all of the watersheds of the Tomahawk river, there are about 100 square miles, or 4% of the watershed under control by reservoirs at Minocqua and Squirrel lakes.

Above Hat Rapids with a watershed of about 1,070 square miles, there are about 480 square miles or 45%, under reservoir control. Above Merrill with a watershed of 2,600 square miles there are about 580 square miles, or 22%, under reservoir control.

Table IV, following, gives the monthly precipitation in inches on the watershed between Hat Rapids and Merrill, from daily observations at six stations, for the years 1906–1910.

The U. S. Geological Survey has taken daily gauge readings of the river, showing the elevation of the water surface, at Merrill since 1903, at Hat Rapids since 1906, and at Necedah since 1903. Having what is termed a rating curve, or graphical relation between discharge and gauge reading, at the given place, the daily gauge readings give the rate of flow in cubic feet per second for the given days. In order to determine the average monthly flow it is most convenient to plat the daily rates of flow for periods of one year, and form curves termed hydrographs of the river. On plates XXV–XXIX, hydrographs of the river are shown for Hat Rapids, Merrill and Necedah for the years 1906–1910. The average monthly rates of flow are indicated both by figures and scale as applied to the hatched portions of the diagrams.

Some uncertainty exists as to the flow in the river under ice conditions. Until further data are available it has been considered advisable to reduce the flows of December, January and February by 30% and of March by 15% of the flow as determined for open channel conditions.

TABLE V.
RUNOFF DATA
FOR THE
UPPER WISCONSIN RIVER WATERSHED
1906 – 1910

Month	Runoff at Merrill		Runoff at Hat Rapids		Runoff from watershed between Hat Rapids-Merrill	
	cu. ft. per sec.	inches on watershed	cu. ft. per sec.	inches on watershed	cu. ft. per sec.	inches on watershed
			1906			
January	2480	1.10	800	0.86	1680	1.27
February	2200	088	700	0.68	1500	1.02
March	2920	1.29	920	0.99	2000	1.51
April	9480	4.07	2000	2.08	7480	5.46
May	6520	2.89	1740	1.88	4780	3.60
June	5320	2.28	1760	1.89	3560	2.60
July	3760	1.67	1040	1.12	2720	2.05
August	3600	1.60	1180	1.27	2420	1.82
September	3480	1.49	980	1.02	2500	1.82
October	3280	1.46	1140	1.23	2140	1.61
November	3000	1.29	880	0.92	2120	1.55
December	2080	0.92	680	0.73	1400	1.05
			1907			
January	1760	0.78	720	0.78	1040	0.78
February	1680	0.67	900	0.88	780	0.59
March	2640	1.17	1040	1.12	1600	1.21
April	6400	2.74	2160	2.25	4240	3.09
May	7090	3.14	2320	2.50	4770	3.60
June	3280	1.41	1440	1.50	1840	1.34
July	2920	1.30	1380	1.49	1540	1.16
August	1800	0.80	840	0.91	960	0.72
September	5130	2.20	1060	1.10	4070	2 97
October	2200	0.98	720	0.78	1480	1 12
November	1680	0.72	660	0.69	1020	0.75
December	1160	0.52	460	0.50	700	0.59
			1908			
January	1160	0.52	600	0.65	560	0.42
February	1560	0.56	680	0.69	680	0.48
March	1640	0.73	800	0.86	840	0.63
April	6450	2.76	1700	1.77	4750	3.47
May	5730	2.54	1660	1.79	4070	3.07
June	4400	1.89	1440	1.50	2960	2.16
July	3200	1.42	1060	1.14	2140	1.62
August	1520	0.67	900	0.97	620	0.47
September	1200	0.52	800	0.83	400	0.29
October	1800	0.80	620	0.67	1280	0.97
November	1240	0.53	540	0.56	700	0.51
December	1280	0.57	500	0.54	780	0.59

Note:- Rate of flow in cu.ft. per sec. per sq.mi. = inches depth per month

TABLE V CONT.
RUNOFF DATA
FOR THE
UPPER WISCONSIN RIVER WATERSHED
1906-1910

Month	Runoff at Merrill		Runoff at Hat Rapids		Runoff from watershed between Hat Rapids-Merrill	
	cu. ft. per sec.	inches on watershed	cu ft. per sec.	inches on watershed	cu ft. per sec.	inches on watershed
			1909			
January	1280	0.57	620	0.67	660	0.50
February	1160	0.46	540	0.53	620	0.42
March	1280	0.57	660	0.71	620	0.47
April	4400	1.89	1000	1 04	3400	248
May	7200	3.19	1880	2.02	5320	4.00
June	3840	1.65	1280	1.33	2560	1.87
July	2440	1.08	1300	1.40	1140	0.86
August	2080	0.92	1620	1.75	460	0.35
September	2000	0.86	1080	1.13	920	0.67
October	1600	0.71	780	0.84	820	0.62
November	4690	2.01	1580	1.65	3110	2.27
December	1920	0.85	820	0.88	1100	0.83
			1910			
January	1480	0.66	860	0.93	620	047
February	1400	0.56	900	0.88	500	0.34
March	2480	1.10	1120	1.21	1360	1.03
April	4080	1.75	1220	1.27	2860	2.09
May	2800	1.24	1060	1.14	1740	1.31
June	1520	0.65	660	0.69	860	0.63
July	1080	0.48	540	0.58	540	0.41
August	880	0.39	530	0.57	350	0.26
September	1280	0.54	620	0.65	660	0.48
October	1400	0.62	560	0.60	840	0.63
November	1250	0.54	560	0.58	690	0.51
December	930	0.41	450	0.48	480	0.36

Summary by years.

Year	Runoff at Merrill	Runoff at Hat Rapids	Runoff from watershed between Hat Rapids-Merrill
	Inches on watershed	Inches on watershed	Inches on watershed
1906	20.94	14.61	25.36
1907	16.43	14.50	17 80
1908	13.51	11.97	14.68
1909	14.76	13.95	15.34
1910	8.94	9.58	8.52

Area of watershed above Hat Rapids = 1070 sq.mi with 10% water surface
" " " " Merrill " 2600 " " 6½ " "
" " " between Merrill and H.R = 1530 " " 4 " "

Table V shows the run-off data for the upper Wisconsin river at Hat Rapids and Merrill, and also for the portion of the river between Hat Rapids and Merrill, for the years 1906–1910. The data are given in cubic feet per second and also in inches depth on the watershed that ran off during the given month. The total run-off in inches depth on the watershed for any given period can easily be obtained by adding the the quantities of run-off during the months of the period.

The watershed between Hat Rapids and Merrill has only about 4% water surface, and being practically free from the effects of artificial storage, the conditions of flow from a land surface alone practically exist.

The data are of too short duration to furnish definite conclusions, but should furnish within reasonable limits, information as to the general relation of rainfall to run-off, the effect of ground storage on uniformity of run-off and the amount of annual evaporation from the soil.

The monthly rainfall and monthly run-off data given, have been platted as shown on Plates XX and XXI. The hatched portions represent the run-off for the various months and years, in inches on the watershed, while the heavy line represents the rainfall. The upper line of figures for each year, gives the variation of the monthly rainfall on the watershed, from the fourteen year average above Merrill. The lower line of figures for each year, gives the rainfall deficiency, or algebraic sum of the variations, from January first, from the fourteen year average above Merrill.

There is no general relation between rainfall and run-off for the short period of one month, due to the extreme range of amount, intensity and distribution of the rainfall throughout the months, and also to the change in elevation of the ground water level during the month considered. In the months of the early spring the run-off increases rapidly as a result of melting of snow and generally exceeds the rainfall for a period of one month, but not usually for a period of two months. The main purpose of the plates is to study the method by which stream flow is maintained and the utility of natural ground storage for increasing the uniformity of stream flow.

Referring to the year 1907, the ordinates to the curved lines, starting with the given average monthly run-off and drawn downward and to the right, represent approximately the rates of run-off, if no rain should occur subsequent to the month for which the respective curves are drawn. The form of these curves, representing the underground flow was determined as follows. In September, 1907, the aver-

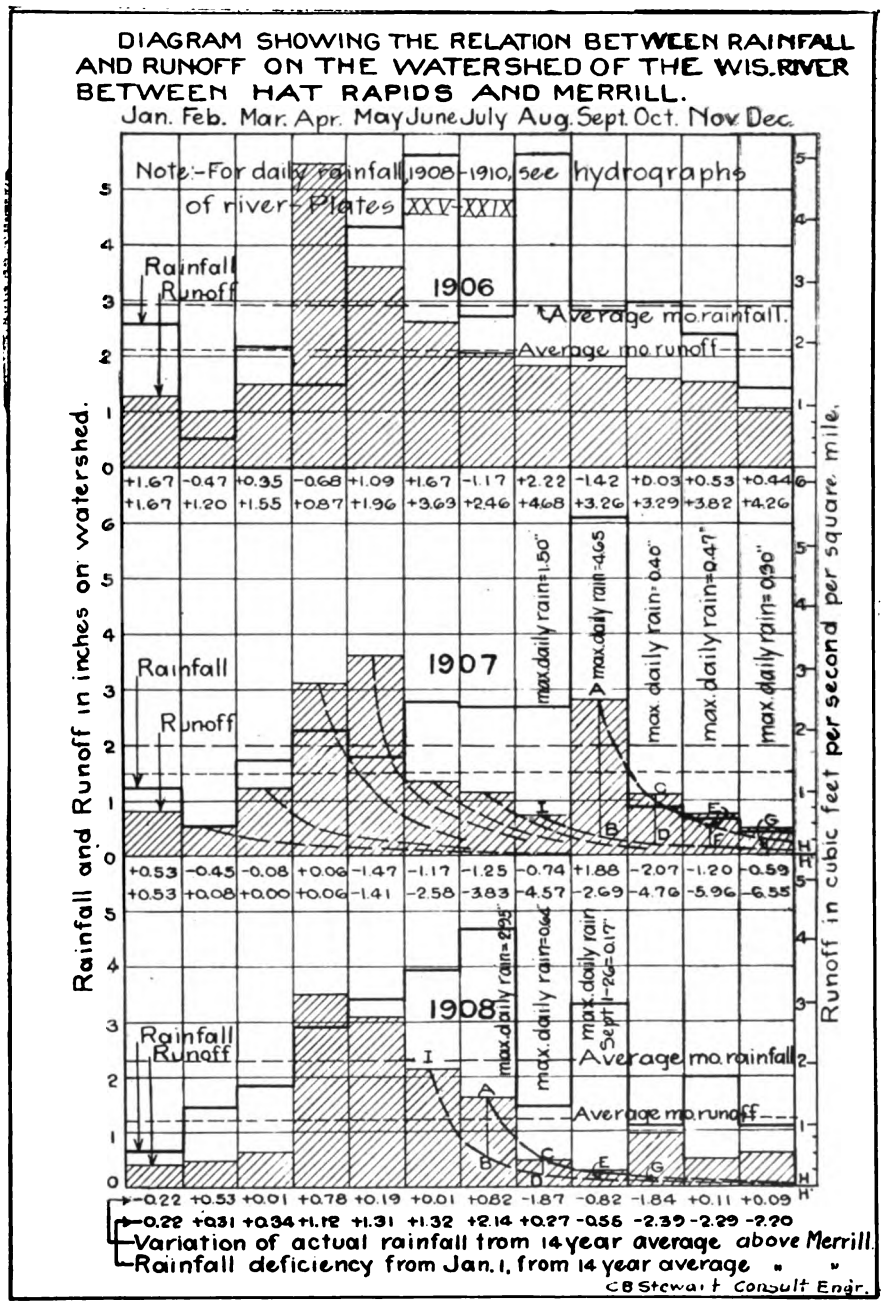


PLATE XX.

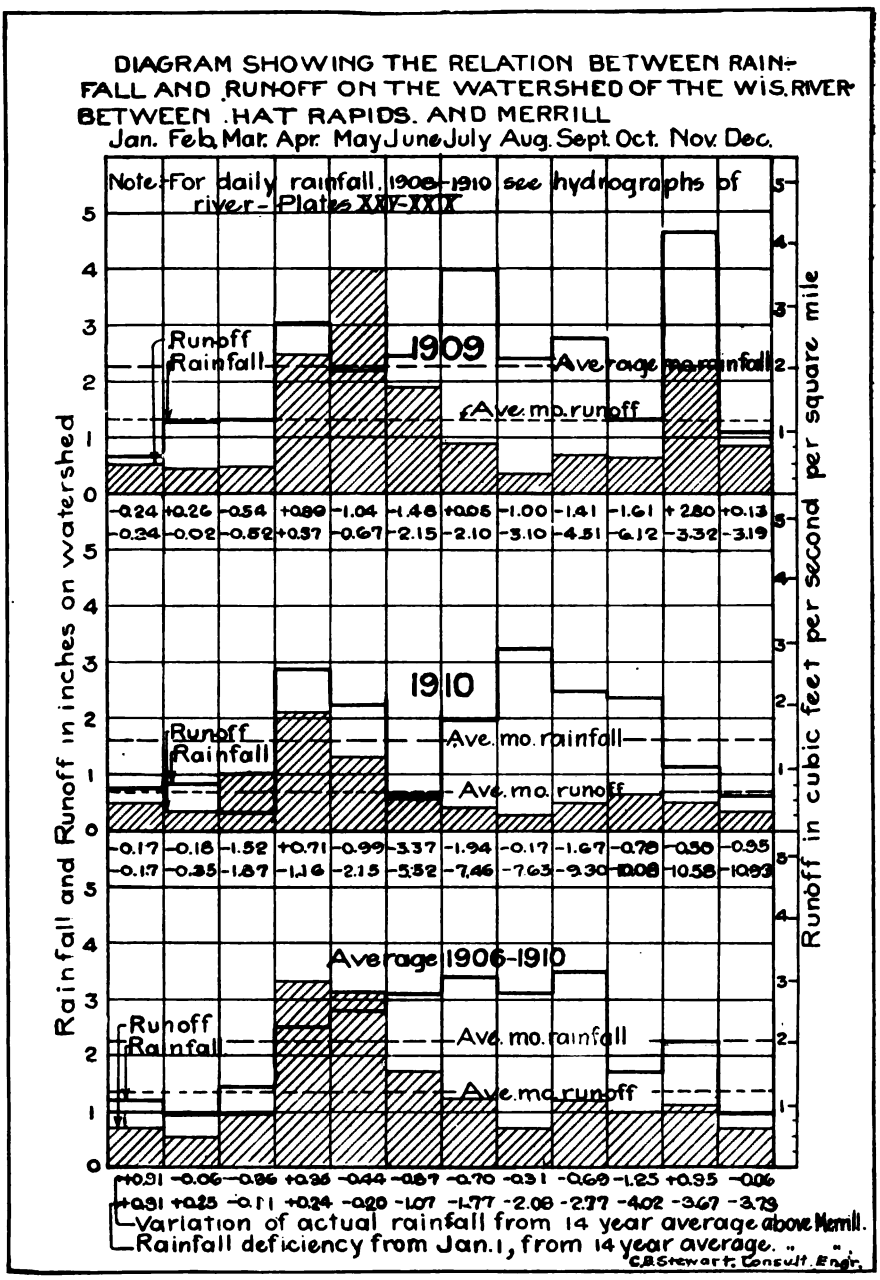


PLATE XXI.

age monthly rainfall was 6.08″, 1.88″ above the fourteen year average. The heavy rains were distributed over a period of about a week near the middle of the month (See Plate XXVI and monthly Climatological Reports of the Weather Bureau for Wisconsin, 1907), the heavier rains at single stations being as follows:

Minocqua, September 15th	4.65″ (Maximum)
Merrill, September 19th	3.75″
Prentice, September 18th	2.49″
Koepenick, September 19th	2.10″
Koepenich, September 18th	2.09″

The rainfall in each of the months, October, November and December was very small, amounting to 0.87″, 0.69″ and 0.42″ respectively (See Table IV). The maximum daily rainfall at any one station in October and November was about 0.40″, with rains at other stations on or about the same dates averaging about 0.20″. The maximum rainfall in December at any one station was 0.30″, with rains at other stations averaging about 0.10″. The amounts and distribution of the rainfall in these months, was such that very little run-off could have resulted therefrom. Estimating the probable values for the run-off from these small rains, the curve A H may be drawn. Ordinates to this curve at points A, C, E, etc., would represent with reasonable accuracy, the run-off for the corresponding months of September, October, November, etc., if no rains had occurred subsequent to September. The ordinates to the curve I H′, similar in form to A H, at I, B, D, F, etc., would represent the run-off for the corresponding months of August, September, October, November, etc., if no rains had occurred subsequent to August. Careful observation of the results of rainfall on the watershed during the summer months, indicates that for rains not exceeding 3″ per day, with a maximum intensity of about 1″ per hour, there would be no surface flow; for rains exceeding this amount the writer as yet can make no definite statement as to the surface flow, except that there are no indications of erosion and infers from this that the surface flow has been but a small percentage of the total run-off. The curve A H would represent approximate underground flow, the approximation being due to the use of the average monthly run-off, for determining the point A of the curve, and which may be slightly influenced by surface flow.

The length of A B represents the average increment to run-off during the month of September, as a result of the 6.08″ of rainfall during September. The length of C D represents the average increment to

run-off in October from ground storage resulting from the 6.08″ rainfall in the month of September. The length of E F represents the average increment to run-off in November, from ground storage resulting from the 6.08″ of rainfall in September. Likewise the increment to the run-off for the month of December is represented by G, while that for the month of January is very nearly 0″.

The results show that with a rainfall of 6.08″ in the month of September a total of about 4.0″ or 65% ran off, with about the following distribution:

Run-off in Sept. = A B	= 2.5″	or	63% of total run-off
Run-off in Oct. = O D	= 0.8″	or	20% of total run-off
Run-off in Nov. = E F	= 0.4″	or	10% of total run-off
Run-off in Dec. = G	= 0.2″	or	5% of total run-off
Run-off in Jan. =	0.1″	or	2% of total run-off
Total run-off.....	= 4.0″	or	100%

Referring to the year 1908 the rainfall during the month of August was very small, being 1.87″ below the fourteen year average, while the rainfall deficiency from January first, 1908, was 0.27″ above the fourteen year average. The rainfall in September, practically all occurred within the last five days of September (See Plate XXVII for distribution of rainfall), so that the larger part of the run-off from the September rains did not occur until October. The curve A H, therefore, represents with reasonable accuracy the underground flow, should no rains have occurred subsequent to the month of July. The curve I H similar in form to A H would represent the underground flow, should no rains have occurred subsequent to June. The lengths of A B, C D, E and G represent respectively the increments to run-off in the months of July, August, September and October, from a rainfall of 4.73″ in the month of July. The total run-off was about 1.65″, made up approximately as follows:

Run-off in July = A B	= 1.10″	or	67% of total run-off
Run-off in Aug. = O D	= 0.30″	or	18% of total run-off
Run-off in Sept. = E	= 0.15″	or	9% of total run-off
Run-off in Oct. = G	= 0.07″	or	4% of total run-off
Run-off in Nov. =	0.03″	or	2% of total run-off
Total run-off.....	= 1.65″	or	100%

From the two cases cited it is reasonable to infer that the effect of ground storage on run-off on the upper Wisconsin river is to dis-

tribute the total run-off that results from rains of from 4″ to 6″ per month in summer time, over a period of about five months, the average monthly run-offs being respectively equal to about 65, 19, 10, 4, and 2% of the total resulting run-off.

The year 1908, January to July inclusive, shows rainfall conditions above the average for fourteen years, then with two very dry months following, the stream flow was 400 cubic feet per second from 1,530 square miles, or 0.26 cubic feet per second per square mile (See Table V). From this it is evident that heavy rains during the spring and early summer months, will not prevent the possibility of depletion of the ground storage during the summer period.

The principal element in maintaining stream flow in the case of the upper Wisconsin river is seen to be the periodic occurrence of rains, each of which adds its portion to the run-off and contributes to the total.

Table VI gives the rainfall and run-off data by periods of the year for the year 1906–1910 for the watershed of the Wisconsin river between Hat Rapids and Merrill. These data are used in Plates XXII and XXIII, and show by means of curves the general relation between rainfall and run-off for the various periods of the year and also for the entire water year. The average of the results for the five years is shown in the following table:

	Rainfall.	Run-off.	Run-off / Rainfall.
First half storage period, (Dec., Jan., Feb.)	3.21	2.08	0.65
Second half storage period, (Mar., Apr., May)	6.77	7.40	1.10
Growing period, (June, July, Aug.)	9.40	3.66	0.40
Replenishing period, (Sept., Oct., Nov.)	7.44	3.32	0.45
Average for 5 years, 1906-1910	26.82	16.46	0.61

The term evaporation from soil, when used in connection with investigations of rainfall and run-off is ordinarily considered as including all losses from the soil, except the run-off. The term thus includes evaporation from soil and water surface, water used by plant life, underground flow or seepage into underlying strata and all other losses. The evaporation from the soil for the watershed under consideration, 1,530 square miles, with about 4% of water surface, for the five years 1906–1910, is seen to have averaged 10.36″ per year. The curve, Plate XXIII, representing the general relation of rainfall to run-off for the water year, shows that the evaporation increases slightly with the rainfall.

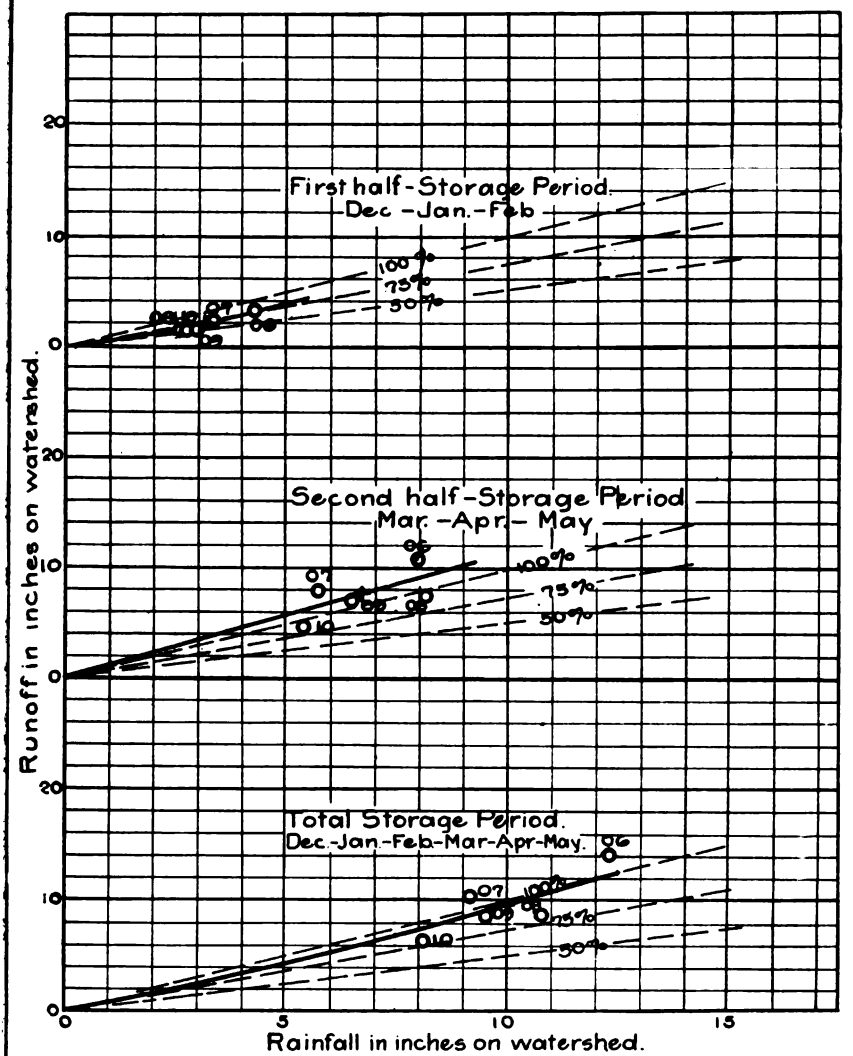
TABLE VI

RAINFALL AND RUNOFF DATA BY PERIODS FOR THE WATERSHED OF THE WISCONSIN RIVER BETWEEN HAT RAPIDS AND MERRILL.

WATER YEARS 1906-1910, (1530 SQ. MI. – 4% WATER SURFACE)

Months	Period	Rainfall in inches	Runoff in inches	Evaporation in inches
1906				
Dec.-Jan.-Feb.	First half Storage	4.31	7.45	
Mar.-Apr.-May	Second " "	7.98	10.57	
	Total Storage	12.29	14.02	
June-July-Aug.	Growing	14.00	6.47	
Sept.-Oct.-Nov.	Replenishing	8.17	4.98	
	Total-Water year	34.46	25.47	8.99
1907				
Dec.-Jan.-Feb.	First half Storage	3.42	2.36	
Mar.-Apr.-May	Second " "	5.73	7.80	
	Total Storage	9.15	10.26	
June-July-Aug.	Growing	8.12	3.22	
Sept.-Oct.-Nov.	Replenishing	7.64	4.67	
	Total-Water year	24.91	18.15	6.76
1908				
Dec.-Jan.-Feb.	First half Storage	2.62	1.43	
Mar.-Apr.-May	Second " "	8.20	7.17	
	Total Storage	10.82	8.60	
June-July-Aug.	Growing	10.24	4.25	
Sept.-Oct.-Nov.	Replenishing	6.48	1.77	
	Total-Water year	27.54	14.62	12.02
1909				
Dec.-Jan.-Feb.	First half Storage	3.01	1.51	
Mar.-Apr.-May	Second " "	6.53	6.95	
	Total Storage	9.54	8.46	
June-July-Aug.	Growing	8.85	3.08	
Sept.-Oct.-Nov.	Replenishing	8.81	3.56	
	Total-Water year	27.20	15.10	12.10
1910				
Dec.-Jan.-Feb.	First half Storage	2.68	1.64	
Mar.-Apr.-May	Second " "	5.42	4.43	
	Total Storage	8.10	6.07	
June-July-Aug.	Growing	5.80	1.30	
Sept.-Oct.-Nov.	Replenishing	6.08	1.62	
	Total-Water year	19.98	8.99	10.99
Average for 5 years 1906 – 1910				
Dec.-Jan.-Feb.	First half Storage	3.21	2.08	
Mar.-Apr.-May	Second " "	6.77	7.40	
	Total Storage	9.98	9.48	
June-July-Aug.	Growing	9.40	3.66	
Sept.-Oct.-Nov.	Replenishing	7.44	3.32	
	Total-Water year	26.82	16.46	10.36

CURVES SHOWING RELATION BETWEEN RAINFALL AND RUNOFF ON THE WATERSHED OF THE WISCONSIN RIVER BETWEEN HAT RAPIDS AND MERRILL.



O Observed values for. given periods in each year(1906-1910 inclusive)
+ Average values for given periods, years(1906-1910) inclusive).

PLATE XXII.

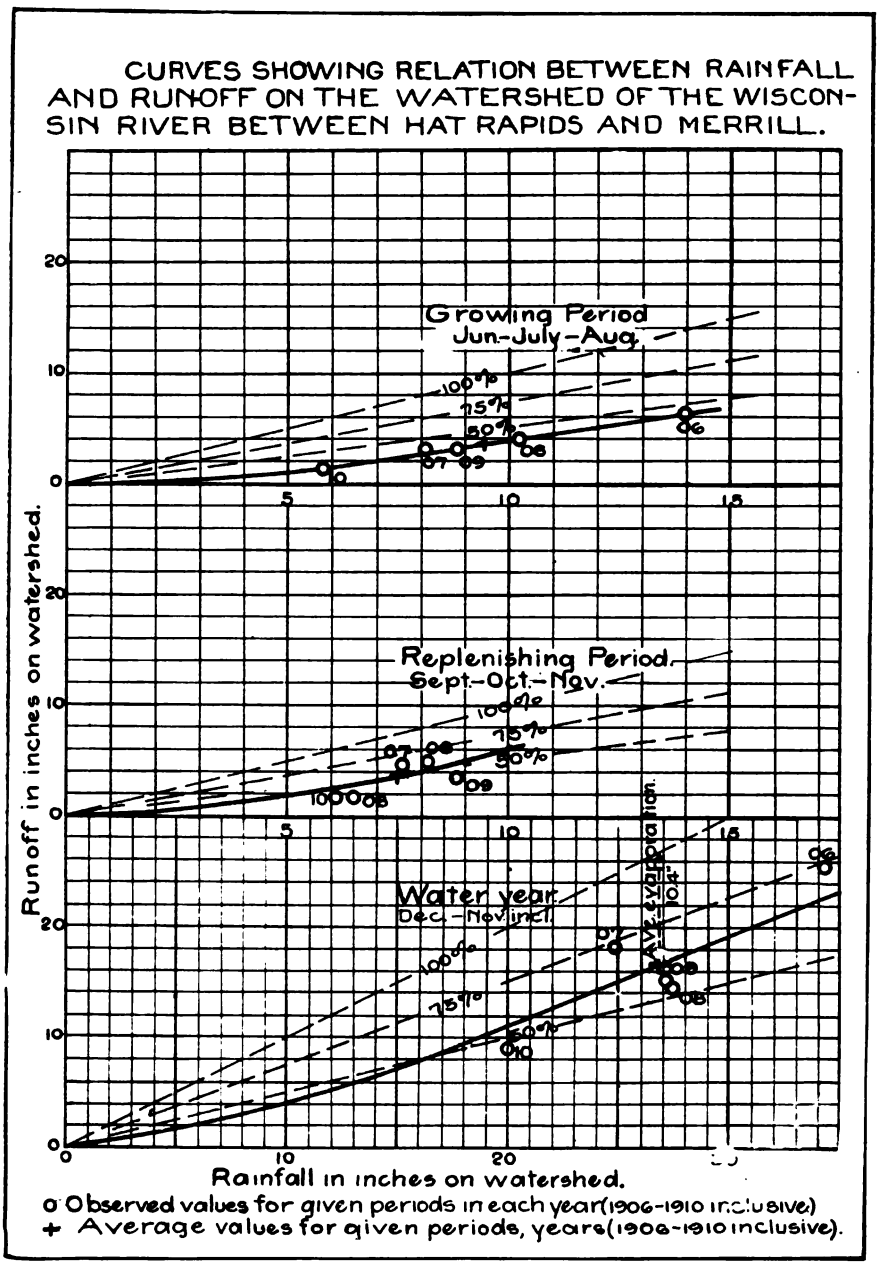


PLATE XXIII.

YIELD OF WATERSHEDS HAVING FROM 0 TO 100% OF WATER SURFACE.

In order to investigate the effect of storage reservoirs at present in operation, and of future reservoir projects on stream flow, it is convenient to arrange the run-off data in the form of curves, termed mass curves, as shown in Plate XXIV. These mass curves afford a graphic means of showing the rate of stream flow at any time, by means of the slope of the curve at the given time. The abscissae represent time and the ordinates represent the summation of monthly run-offs in inches depth on the watersheds, the rates of flow being considered uniform during the periods of one month. A rate of run-off of one inch per month, equal to twelve inches per year, would be represented by the slope of the straight line A B. From the 12″ depths per year, the rate of run-off in cubic feet per second for each square mile can be computed. In this way the draft diagram shown was constructed, the slope of each line representing a definite rate of flow. The rate of flow at any time is most conveniently spoken of as inches depth per year from the watershed, and is applicable to a watershed of any area. When a watershed of definite area is considered, the rate of flow in foot second units may easily be obtained by multiplying the area in square miles by the flow in cubic feet per second per square mile, corresponding to the given rate in inches depth per year.

Curves numbered 2, 3 and 4 are direct results from daily gauge readings of the river at Hat Rapids and Merrill, the data being given in Table V. Curves numbered 1, 5, 6 and 7 are deduced from curve number 2, by allowing for the rainfall and evaporation on the part of the watershed occupied by water surface and making proper allowance for the remaining land surface. The most extensive experiments to date on evaporation from a water surface were made by Mr. Desmond Fitzgerald in connection with the Boston Water Works, 1876–1889. A maximum yearly evaporation was found equal to about forty-three inches, the minimum about thirty-four inches, and the average annual evaporation for the sixteen years about 39.2″. From observations at Rochester, New York, by Mr. E. Kuichling extending over about eight years, the average annual evaporation was about 34.5″. This practically completes the list of reliable experiments on evaporation under conditions similar to those in the central states and eastern states. Readings of

dry-and wet-bulb thermometers at various Signal Service stations taken in 1887 (See Monthly Weather Review, 1888), indicate that the evaporation in the upper lake region is slightly less than in the eastern states and averaged for this one year about 28″. The U. S. Geological Survey are at present making measurements of evaporation in Wisconsin at Menasha, Winnebago county, at Montello, Marquette county, and at Madison, Dane county. The results of these measurements are not as yet in condition for publication, but indicate that the average annual evaporation is about 30″. For the purpose of the present investigation the average annual evaporation has been assumed as equal to 30.5″, the same as the average annual rainfall for the fourteen year period 1896–1909. The distribution of annual evaporation in the various months has been taken approximately the same as for the eastern states.

By taking the algebraic sum of the rainfall on the water surface and evaporation from the water surface for the various months of the years considered, the net monthly yields from the water surface may be determined. This would be either positive or negative, depending on whether the rainfall or evaporation is the greater. Table VII gives the monthly yields from a water surface for the dry years 1907–1910.

Curve number 2, Plate XXIV, shows the yield for the years 1907-1910 from the watershed between Hat Rapids and Merrill, comprising 1,530 square miles and having approximately 96% of land surface and 4% of water surface. It is desirable to determine from the data from which this curve is constructed, the yield from a watershed composed entirely of land surface. Considering any given month, the yield from a water surface in inches depth may be found from Table VII. Assume this yield distributed over the entire watershed by taking 4% of the values in the table. Subtract this value from the actual yield of the watershed, and the result will be the yield from the land surface, which occupied 96% of the watershed. Divide this by 0.96 and the result will be the yield in inches depth from an all land surface. Table VIII gives these computed monthly yields for the years 1907–1910. The data are represented graphically by curve number 1, which shows that for the four dry years the average annual run-off, from an all land surface, was about 15″. Curve number 3 represents the measured run-off at Merrill; the effect of 6½% of water surface is seen to have decreased the average annual run-off to about 14″. Curve number 4 represents the measured run-off at Hat Rapids; the effect of 10% of water surface is seen to have decreased the average annual run-off

TABLE VII.

MONTHLY YIELDS FROM AN ALL WATER SURFACE

COMPUTED FROM RAINFALL AND EVAPORATION ON THE WATERSHED OF THE WISCONSIN RIVER BETWEEN HAT RAPIDS AND MERRILL

DRY YEARS 1906–1910

Values given in inches depth

Month	1906			1907			1908			1909			1910		
	Rainfall	Evaporation.	Net yield	Rainfall	Evaporation.	Net yield	Rainfall	Evaporation	Net yield	Rainfall	Evaporation	Net yield	Rainfall	Evaporation	Net yield.
January	2.56	0.50	2.06	1.42	0.50	0.92	0.67	0.50	0.17	0.65	0.50	0.15	0.72	0.50	0.22
February	0.53	0.50	0.03	0.55	0.50	0.05	1.53	0.50	1.03	1.26	0.50	0.76	0.82	0.50	0.32
March	2.17	1.25	0.92	1.74	1.25	0.49	1.83	1.25	0.58	1.28	1.25	0.03	0.30	1.25	-0.95
April	1.47	2.25	-0.78	2.21	2.25	-0.04	2.93	2.25	0.68	3.04	2.25	0.79	2.86	2.25	0.61
May	4.34	3.50	0.84	1.78	3.50	-1.72	3.44	3.50	-0.06	2.21	3.50	-1.29	2.26	3.50	-1.24
June	5.62	4.25	1.37	2.78	4.25	-1.47	3.96	4.25	-0.29	2.47	4.25	-1.78	0.58	4.25	-3.67
July	2.74	4.75	-2.01	2.66	4.75	-2.09	4.73	4.75	-0.02	3.96	4.75	-0.79	1.97	4.75	-2.78
August	5.64	4.75	0.89	2.68	4.75	-2.07	1.55	4.75	-3.20	2.42	4.75	-2.33	3.25	4.75	-1.50
September	2.76	3.75	-0.97	6.08	3.75	2.33	3.38	3.75	-0.37	2.79	3.75	-0.96	2.53	3.75	-1.22
October	2.97	2.75	0.22	0.87	2.75	-1.88	1.10	2.75	-1.65	1.33	2.75	-1.42	2.16	2.75	-0.59
November	2.42	1.25	1.17	0.09	1.25	-0.56	2.00	1.25	0.75	4.69	1.25	3.44	1.08	1.25	-0.17
December	1.45	1.00	0.45	0.42	1.00	-0.58	1.10	1.00	0.10	1.14	1.00	0.14	0.66	1.00	-0.34

Annual evaporation assumed = 30.5

TABLE VIII.

MONTHLY YIELDS FROM AN ALL LAND SURFACE

COMPUTED FROM RUNOFF FROM THE WATERSHED OF THE WISCONSIN RIVER BETWEEN HAT RAPIDS AND MERRILL. DRY YEARS 1906-1910.

Values given in inches depth.

Month	1906				1907				1908				1909				1910			
	Measured Runoff	Runoff 4% water sur	Runoff 96% land sur	Runoff all land sur	Measured Runoff	Runoff 4% water sur	Runoff 96% land sur	Runoff all land sur	Measured Runoff	Runoff 4% water sur	Runoff 96% land sur	Runoff all land sur	Measured Runoff	Runoff 4% water sur.	Runoff 96% land sur	Runoff all land sur	Measured Runoff	Runoff 4% water sur	Runoff 96% land sur	Runoff all land sur
Jan.	1.27	0.10	1.17	1.22	0.78	0.04	0.74	0.77	0.42	0.01	0.41	0.43	0.50	0.01	0.49	0.51	0.47	0.01	0.46	0.48
Feb.	1.02	0.00	1.02	1.07	0.53	0.00	0.53	0.55	0.48	0.04	0.44	0.46	0.42	0.03	0.39	0.41	0.34	0.01	0.33	0.34
Mar.	1.51	0.04	1.47	1.53	1.21	0.02	1.19	1.24	0.63	0.02	0.61	0.64	0.47	0.00	0.47	0.49	1.03	-0.04	1.07	1.12
Apr.	5.46	-0.03	5.49	5.71	3.09	0.00	3.09	3.22	3.47	0.03	3.44	3.59	2.48	0.03	2.45	2.55	2.09	0.02	2.07	2.16
May	3.60	0.03	3.57	3.72	3.60	-0.07	3.67	3.82	3.07	0.00	3.07	3.20	4.00	-0.05	4.05	4.22	1.31	-0.05	1.36	1.42
June	2.60	0.05	2.55	2.66	1.34	-0.06	1.40	1.46	2.16	-0.01	2.17	2.26	1.87	-0.07	1.94	2.02	0.63	-0.15	0.78	0.81
July	2.05	-0.08	2.13	2.22	1.16	-0.10	1.26	1.31	1.62	0.00	1.62	1.69	0.86	-0.03	0.89	0.93	0.41	-0.11	0.52	0.54
Aug.	1.82	0.04	1.78	1.85	0.72	-0.08	0.80	0.83	0.47	-0.13	0.60	0.63	0.35	-0.09	0.44	0.46	0.26	-0.06	0.32	0.33
Sept.	1.82	-0.04	1.86	1.94	2.80	0.09	2.71	2.82	0.29	-0.01	0.30	0.31	0.67	-0.04	0.71	0.74	0.48	-0.05	0.53	0.55
Oct.	1.61	0.01	1.60	1.67	1.12	-0.08	1.20	1.25	0.97	-0.07	1.04	1.08	0.62	-0.06	0.68	0.71	0.63	-0.02	0.65	0.68
Nov.	1.55	0.05	1.50	1.56	0.75	-0.02	0.77	0.80	0.51	0.03	0.48	0.50	2.27	0.14	2.13	2.22	0.51	-0.01	0.52	0.54
Dec.	1.05	0.02	1.03	1.07	0.53	-0.02	0.55	0.57	0.59	0.00	0.59	0.62	0.83	0.01	0.82	0.85	0.36	-0.01	0.37	0.39

Note:-Watershed between Hat Rapids and Merrill is approximately 96% land surface and 4% water surface.

to about 12½". Curves numbered 5, 6 and 7 represent respectively the run-off from watersheds having 14, 25, and 50% of water surface, and were computed from curve number 1, by adding algebraically the monthly yields of the given percentages of land and water surface, each being considered as distributed over the entire watershed. For a drainage area having about fifty per cent of water surface, the average annual run-off for the four dry years was about 4½". The effect on stream flow of having a watershed with a large percentage of water surface is seen to be very marked, and beyond certain limits would be a decided disadvantage.

EFFECT OF STORAGE RESERVOIRS ON STREAM FLOW.

On the 580 square miles of drainage area under control by the reservoirs of the Wisconsin Valley Improvement company, there are about 84 square miles of water surface, thus making about 14% of water surface on the drainage area. Of this 84 square miles of water surface, about 58 square miles or 10% of the drainage area is made up of lakes used for storage reservoirs. Curve number 5 has been drawn to represent the average conditions of these lakes under control. The upper line represents the regulated discharge from the reservoir in cubic feet per second per square mile. In July, 1908, the gauge readings on the reservoirs showed that there was approximately 4,200 million cubic feet in storage. The reservoirs were very nearly filled, and for present purposes they will be considered so and spoken of as having a depletion of 0" when filled to this extent. The draft on the storage during the summer season, 1908, as determined from the readings of the gauges was 3,480 million cubic feet. The ordinates on the diagram represent inches on the watershed, and 1" on 580 square miles would equal 1,350 million cubic feet. The draft of 3,480 million cubic feet would therefore represent a depletion of 2.58". The rate of discharge may be considered uniform during the period of draft. The divergence of the discharge line from the run-off curve (net supply to the reservoir, including rainfall and evaporation on the water surface), measured vertically, will represent the amount of depletion at any time in inches depth on the watershed. The period and amount of depletion being known, the rate of discharge may be determined graphically. The gates of the reservoir were closed during the last half of October and all of November, so the discharge line becomes horizontal during this time; water is collected in the reservoirs and the depletion decreased from 2.58" to 1.5". The gates were then gradu-

ally opened and by the last of March, 1909, the reservoirs were emptied. The depletion at this time, March 30, is known to have been 4,200÷1,350=3.1″. From the data given, the discharge line can then be adjusted. The gates were then partially closed, and by the end of June the reservoirs were filled to practically the same amount, 4,200 million cubic feet, or zero depletion, as in the previous spring.

The total storage capacity on these lakes is about 5,000 million cubic feet, giving an average fluctuation of lake level of about *three feet*. Were these lakes in a condition of nature, without dams at their outlets, there would be a natural fluctuation of lake level and resulting natural storage. The amount of this natural fluctuation of lake levels cannot be known, as it would depend on local conditions. Experience from similarly located lakes would indicate that in a condition of nature there would be a fluctuation of about 1½ feet, or about one-half that obtained by regulation. This would give a storage capacity of about 2,500 million cubic feet in excess of natural storage, and from which actual benefit would be obtained.[1] In the diagram, curve number 5, the medial line, represents the approximate discharge that would have occurred were the lakes in a condition of nature. As the reservoirs occupy about 10% of the watershed, a depletion of 3.1″ for the 4,200 million cubic feet would represent a fluctuation of 31″ on the reservoirs. The medial line would represent conditions for a fluctuation of 15½″ on the reservoirs.

The increase in stream flow in cubic feet per second per square mile can be taken from the diagram for the summer and winter seasons. This increase multiplied by 580, the area of the watershed under control, gives the increase in flow in cubic feet per second over that which would result under natural conditions. Table IX shows the benefits from increase of stream flow obtained since the summer season, 1908. The increase in water horse power and cost per water horse power for the time of service are also given. The column headed total cost is made up of cost of maintenance and 6% interest on the capital stock paid in, as shown by the reports of the secretary of the Wisconsin Valley Improvement company.

Plates XXV-XXIX are hydrographs of the Wisconsin river at Hat Rapids, Merrill and Necedah for the years 1906–1910. Those for the years 1908–1910 show graphically the effect of increase of stream flow during the summer and winter seasons. The ratio of the increase of

[1] This method is equivalent in result to assuming that, on the average, the effects of evaporation from the lake surfaces and natural storage, are such as to leave the actual benefits as obtained from 50 per cent of the available storage draft.

flow to the average monthly flow at any time for the three places, Hat Rapids, Merrill and Necedah, may readily be computed from the diagram. Omitting the year 1910, because of incompleteness in the winter season, the average yearly storage draft for the two years, 1908–1909, has been 5,840 million cubic feet. The benefit from this storage has been an increase of stream flow over that with natural storage, at and below Tomahawk of about 160 cubic feet per second, distributed over seven months.[2] This 160 cubic feet per second would produce for each foot of head utilized, 18 water H. P. or about 13½ actual H. P. A water power plant utilizing 20′ head would then have an increase in available power of about 360 water H. P. or 270 actual H. P. for seven months of the year. The cost of this power for the two years, 1908–1909, has averaged about five dollars per water H. P. for seven months' service.

LOSS BY EVAPORATION FROM THE SURFACE OF RESERVOIRS.

The approximate losses from the water surfaces of the reservoirs due to evaporation during the periods of draft, may be determined from Table VII by summing the yields of the water surface for the months of the respective periods. The percentage of storage lost during the periods of draft from this cause, would be determined from the ratio of the loss, in inches depth, to the total draft, in inches depth, during the periods. The results for the years 1908–1910 were approximately as follows.

2½ months, summer season, 1908.....	loss 4.39″	draft 25.8″	percentage loss = 17
4 months, winter season, '08-09.....	gain 1.04″	draft 16.0″	percentage gain = 6
4 months, summer season, 1909.....	loss 5.50″	draft 20.4″	percentage loss = 27
4 months, winter season, '09-10.....	gain 0.14″	draft 24.4″	percentage gain = 0
8½ months, summer season, 1910.....	loss 8.57″	draft 11.0″	percentage loss = 78

The large percentage loss in 1910 was obviously due to the lack of rainfall, large evaporation and also to the small amount of storage available.

[2]Approximate percentage increase in flow for 7 month at Hat Rapids $= \frac{160}{600} \times 100 = 28.$

Approximate percentage increase in flow for 7 months at Merrill $= \frac{160}{1300} \times 100 = 12.$

Approximate percentage increase in flow for 7 months at Necedah $= \frac{160}{3000} \times 100 = 5.$

TABLE IX.

BENEFITS AND COST OF OPERATION
OF THE
STORAGE RESERVOIRS UNDER THE CONTROL OF THE WIS.VAL.IMP. CO.
YEARS 1908-1910

Season	Storage draft million cu.ft.	Total head utilized	Increase in flow cu.ft. per sec.	Period of service	Increase in water H.P.	Total cost	Cost per W.H.P.
Summer 1908 Aug 1 - Oct. 15	3480	193'	270	2 1/2 mo's.	5900	$ 7645	$1.30 for 2½ mo's
Winter '08-'09 Dec. 1 - Apr. 1	2160	200'	105	4 months	2380	$ 8413	$3.50 for 4 mo's
Summer '09 July 1 - Nov. 1	2750	235	130	4 months	3460	$ 9479	$2.75 for 4 mo's
Winter '09-'10 Dec. 15 - Apr. 1	3200	244	180	3 1/2 months	4950	$ 10680	$2.16 for 3½ mo's
Summer '10 May 15 - Sept. 1	1450	276	80	3 1/2 months	2500	$ 9089	$3.60 for 3½ mo's

Note:- The storage draft, given, represents the volume withdrawn from the reservoirs, as computed from the readings of gages on the reservoirs.

The benefit of increase of stream flow, given, is the approximate increase over the flow with natural storage.

Note.—The values given, "Increase in flow," may be obtained by assuming that on the average ½ or 50 % of the storage draft represents benefits to power plants, and was distributed over the periods of service given.

Curves showing the losses from the water surface of the reservior from rainfall and evaporation, have been drawn in each of the cases of watersheds having 14%, 25% and 50% of water surface. In the case of the watershed having 50% of water surface, it is seen that for a series of dry years the maximum regulated flow could not exceed a rate of about 4½″ per year, and that practically all of the depletion in the reservoir would be caused by evaporation. The regulated flow would be equal approximately to the supply from the land surface part of the watershed. Were the watershed an all land surface, the approximate rate of run-off could be determined from Table VIII giving the yield of an all land surface. The minimum monthly run-off is seen to have occurred in September, 1908, and equalled 0.31″ per month, or a rate of 3.72″ per year. The average yield for the eight months, August to March inclusive, would have been 0.57″ per month, or a rate of 6.84″ per year. The condition of an all land surface with no regulation would thus have been preferable to that of a 50% water surface with regulation.

HYDRAULIC INVESTIGATIONS FOR FUTURE RESERVOIR PROJECTS.

Experience during dry years in Wisconsin has shown the great importance of enlarging the storage reservoir system. There are on the Wisconsin river, at present, about 580 square miles of watershed under control, all of which are at the headwaters of the main river or its branches. In order to obtain any material increase in storage capacity, it will be necessary to construct reservoirs at several points along the main river or its branches, so as to intercept drainage areas of considerable extent. The feasibility of the reservoirs, and actual limits of storage capacity, can only be determined after both topographical and hydraulic data are available. The hydraulic data are a very importnt element in the solution of the problem and must be collected and systematized before a conclusion can be reached.

The results of the investigation of the yield of the watershed of the upper Wisconsin river, Plate XXIV, show that for dry years the maximum regulated flow at or in the vicinity of Hat Rapids cannot exceed a rate of flow of 950 cubic feet per second, as determined from an average annual run-off of about 12″.

In order to obtain information in regard to the maximum, minimum and average run-off of the river for as long a period of years as possible, deductions have been made as shown in Plate XXX. The average monthly run-off data for Merrill and Hat Rapids commence with the years 1903 and 1906 respectively. The available rainfall data commence with the year 1896. It has been shown that there is a general relation between rainfall and run-off. The rainfall and run-off data for Merrill for the years 1903–1910 are shown in Table X. The data of these eight years for Merrill have been plotted as shown in Plate XXX, and a curve drawn showing the general relation between rainfall and run-off. By using this curve, the approximate yearly run-off for the years previous to 1903 may be obtained, when the rainfall is known. These interpreted yearly run-off data, together with the measured monthly run-off data, have been arranged in the form of a mass curve.

TABLE X
RAINFALL AND RUNOFF DATA
FOR
THE WATERSHED OF THE WISCONSIN RIVER, MERRILL AND ABOVE.
YEARS 1903-1910.

Month	1903			1904			1905			1906			1907			1908			1909			1910		
	Average Rainfall in inches	Average Runoff in Cu.ft.per sec.	Total Runoff in inches on watershed	Average Rainfall in inches	Average Runoff in Cu.ft.per sec.	Total Runoff in inches on watershed	Average Rainfall in inches	Average Runoff in Cu.ft.per sec.	Total Runoff in inches on watershed	Average Rainfall in inches	Average Runoff in Cu.ft.per sec.	Total Runoff in inches on watershed	Average Rainfall in inches	Average Runoff in Cu.ft.per sec.	Total Runoff in inches on watershed	Average Rainfall in inches	Average Runoff in Cu.ft.per sec.	Total Runoff in inches on watershed	Average Rainfall in inches	Average Runoff in Cu.ft.per sec.	Total Runoff in inches on watershed	Average Rainfall in inches	Average Runoff in Cu.ft.per sec.	Total Runoff in inches on watershed
January	0.48	720	0.32	0.40	2440	1.08	1.21	2120	0.94	1.85	2480	1.10	1.24	1760	0.78	0.65	1160	0.52	0.53	1280	0.57	0.76	1480	0.66
February	0.54	640	0.26	1.34	2560	1.06	0.65	1960	0.78	0.54	2200	0.88	0.54	1680	0.67	1.73	1360	0.56	1.26	1160	0.46	0.97	1400	0.56
March	2.45	3760	1.67	1.62	3080	1.36	1.38	3080	1.37	2.00	2920	1.29	1.45	2640	1.17	1.85	1640	0.73	1.29	1280	0.57	0.29	2480	1.10
April	2.27	5280	2.27	2.08	5850	2.52	1.15	6900	2.96	1.49	9480	4.07	2.25	6400	2.74	3.04	6450	2.76	2.95	4400	1.89	2.46	4080	1.75
May	5.49	6730	2.98	5.86	8570	3.80	3.83	5650	2.51	4.76	6520	2.89	1.23	7090	3.14	3.00	5730	2.54	2.11	7200	3.19	2.42	2800	1.24
June	1.65	6100	2.62	5.78	6200	2.66	7.32	10600	4.55	5.07	5320	2.28	2.01	3280	1.41	3.66	4400	1.89	3.36	3840	1.65	0.38	1520	0.65
July	5.47	4950	2.19	3.54	3440	1.52	2.45	5480	2.43	2.39	3760	1.67	2.81	2920	1.30	4.46	3200	1.42	5.26	2440	1.08	2.13	1080	0.48
August	6.39	3000	1.33	4.36	3720	1.65	5.65	3800	1.69	4.91	3600	1.60	2.61	1800	0.80	1.28	1520	0.67	2.41	2080	0.92	3.06	880	0.39
September	7.56	8700	3.73	7.05	4800	2.06	3.86	4800	2.06	2.47	3480	1.49	6.65	5130	2.20	3.66	1200	0.52	2.45	2000	0.86	2.40	1280	0.54
October	2.38	6120	2.72	5.43	7200	3.18	2.02	4600	2.04	2.45	3280	1.46	0.73	2200	0.98	0.94	1800	0.80	1.71	1600	0.71	2.12	1400	0.62
November	0.86	2560	1.10	0.29	3040	1.30	1.75	3080	1.32	2.60	3000	1.29	0.52	1680	0.72	1.47	1240	0.53	4.48	4690	2.01	1.12	1250	0.54
December	0.59	1720	0.76	2.45	1480	0.66	1.06	2400	1.06	1.10	2080	0.92	0.52	1160	0.52	1.09	1280	0.57	0.93	1920	0.85	0.83	930	0.41
Total	36.13		21.95	40.20		22.85	32.33		23.71	31.63		20.94	23.16		16.43	26.83		13.51	28.79		14.76	18.94		8.94

The mass curve for Hat Rapids has been drawn in a similar manner. The data from the plate are shown by the following summary:

Rainfall and run-off data.	Hat Rapids.	Merrill.
Average yearly rainfall, 15 years	.....	29.67
Average yearly run-off, 15 years	16.82	17.87
Ratio average run-off to average rainfall, 6% water surface	.....	0.60
Ratio average run-off to average rainfall, 10% water surface	0.56	.....
Maximum yearly run-off, 15 years	25.60	27.60
Minimum yearly run-off, 15 years	9.30	9.30
Approximate ratio of maximum run-off to minimum run-off	2.75	3.00
10″ yearly run-off recurs about once in 20 years.		
12″ yearly run-off recurs about once in 10 years.		

Table XI shows the results of the investigation to determine the effect on stream flow of additional storage reservoirs at various places and for the stated regulation. A regulation of 8″ at Hat Rapids (See Plate XXIV) would mean that the minimum rate of flow would not be less than a rate computed from an annual run-off of 8″ from the watershed of 1070 square miles, and would equal 645 cubic feet per second. Taking the years 1908–1909 as typical, this would require a reservoir of one billion cubic feet capacity at or in the vicinity of Hat Rapids. The increase in stream flow would average 80 cubic feet per second for the five driest months of the year. The increase in power for 300 feet head would amount to 2,730 water H. P. for the five months' period. Complete regulation at Hat Rapids, in dry years would require additional reservoir capacity to the amount of 6¼ billion cubic feet. This would maintain the stream flow at a rate of 950 cubic feet per second, and would give an increase in stream flow at and below Hat Rapids of 300 cubic feet per second during the eight driest months of the year. The increase in power for the 300 feet head would amount to 10,250 water H. P. for the eight months' period.

Complete regulation at Tomahawk in dry years, would require additional reservoir capacity to the amount of 13½ billion cubic feet. This would give an increase in stream flow at and below Tomahawk of 650 cubic feet per second during the eight driest months of the year,

Complete regulation at Merrill in dry years would require additional reservoir capacity to the amount of 20 billion cubic feet. This would give an increase in stream flow at and below Merrill of 965 cubic feet per second for the eight driest months of the year.

The last column of Table XI gives for each case considered the probable minimum yearly returns from the sale of storage power, at five

dollars per water H. P. for the portion of the year. The rate of five dollars for water H. P. for five to eight months' service, has been assumed as a probable minimum rate for the sale of storage power, and must be taken as subject to change, should further investigation show that a higher rate would be necessary to yield a reasonable return on the investment.

It is very important that the State should gain information at an early date in regard to the storage problem on all of its main rivers. All natural basins at the headwaters of the Wisconsin river should be carefully investigated and if found more suitable for storage purposes and for benefit to the river as a whole, than for local power development, the site can be reserved and developed accordingly.

The U. S. Government engineers made preliminary surveys for reservoir sites at the headwaters of the Wisconsin, Chippewa and St. Croix rivers in 1880, and reported available storage capacities to the amounts of 19, 25 and 34 billion cubic feet respectively. Conditions of development along the shores of the lakes and rivers since then, however, have probably progressed to such a point that it will be impossible to obtain one-half of what may then have been feasible.

TABLE XI

INVESTIGATION OF STORAGE RESERVOIRS AND STREAM FLOW ON THE WISCONSIN RIVER

Amount of additional reservoir capacity in billion cu. ft.	Reservoirs at or above	Drainage area in sq. miles	Present approx. ave. min. flow for portion of dry year in cu. ft./sec.	Approx. flow for portion of dry year for stated regulation. cu. ft/sec.	Approx. ave. increase in flow for portion of dry year in cu. ft. per sec.	Approx. ave. increase in 24 hr. H.P. 300' head			Probable min. yearly returns from sale of storage power at $5.00 per W.H.P. for portion of year
						Water H.P.	Actual H.P. Eff. 75%	mo's service	
1	Hat Rapids	1070	565 for 5 mos.	645 for 8"	80 for 5 mos.	2730	2040	5	$ 13650
3	Hat Rapids	1070	580 " 6 "	775 " 10"	195 " 6 "	6635	5000	6	$ 33175
6 ¼	Hat Rapids	1070	650 " 8 "	950 " 12"	300 " 8 "	10250	7700	8	$ 51250
13 ½	Tomahawk	1900	1070 " 8 "	1700 " 12"	650 " 8 "	22050	16500	8	$ 110250
20	Merrill	2600	1545 " 8 "	2310 " 12"	965 " 8 "	32700	24500	8	$ 163500

Note:- Data from mass curves, Plates XXIV - XXX, years 1908-1909 taken as typical.

12" regulation means a rate of flow computed from a 12" annual runoff. See draft diagram Plate XXIV

CONCLUSIONS AND RECOMMENDATIONS.

It should be the policy of the State to encourage to the fullest possible extent both the summer resort business and the development of the water powers along the river.

There is an apparent conflict on some of the lakes between the summer resort interests and the water power interests in that the former desire the minimum fluctuation during the summer season, while the latter desire the maximum; however, by limiting the low water levels during the summer and by the dredging of thoroughfares as proposed, conditions quite favorable to the summer resort interests will be secured.

When more storage becomes available from additional reservoirs it will be possible to hold up the summer level on all of the more important lakes until the latter part of the summer season, thus accommodating the summer resort interests without material decrease in benefit to the water power interests.

In this matter it should in justice be stated that the results of investigation have shown that the Wisconsin Valley Improvement company has been acting in good faith, has in all cases investigated kept within its legal rights and has shown a willingness to co-operate with the summer resort interests by sharing the expenses incident to maintaining suitable boating conditions on these lakes and thoroughfares.

Referring to Table II, it is recommended that the Wisconsin State Board of Forestry accept the high and low water limits of lake levels as outlined for the winter and summer seasons, also the months of the year, where specified, that shall constitute the summer season; also that the Board order established such monuments as specified for the high and low water limits of lake levels. It should be noted that high and low water monuments for lakes Big St. Germain and North Pelican are not proposed in the table.

Referring to Lake Big St. Germain, it is recommended that the lake level limits proposed be accepted temporarily, but that before

monuments are placed, further investigation be made to see if it would not be feasible to secure more favorable conditions for all parties concerned. It is suggested that should a shorter summer season be specified, a higher summer level during this time could be maintained, and that in compensation therefor it may be possible to secure a higher high water limit in both winter and summer seasons.

Referring to North Pelican lake, it is recommended that more data should be collected relative to high water conditions before monuments are established.

Referring to Twin lakes, it is recommended that the proposed agreement of the Wisconsin Valley Improvement company and the summer resort interests to construct permanent piers with sheet piling on each side of the thoroughfare between Big Twin and Little Twin lakes be accepted.

Referring to Long lake on Deerskin river, it is recommended that the proposed agreement of the Wisconsin Valley Improvement company and summer resort interests to co-operate on equal terms in the matter of dredging and maintaining the thoroughfare between Long lake and Sand lake, so as to secure a depth of not less than 2 feet during the specified summer season, be accepted.

It is recommended that, for the present, wooden gauge boards with scale marked in feet and inches, be used for monuments, the elevation of the zero of the scale on the gauge board, to be referred to some object having a permanent elevation. A cloth sign, giving information as to high and low water marks and the months constituting the summer season, may be tacked on some nearby object.

It is recommended that the State Board of Forestry keep in close touch with the operation of the reservoirs, and receive monthly reports from the Wisconsin Valley Improvement company stating the levels on the various lakes.

It is recommended that the Wisconsin State Board of Forestry emphasize the importance of securing additional data on stream flow and evaporation. Additional stream flow data should be obtained on the Wisconsin river at Otter Rapids, near the municipal water power plant of Eagle River, and at some point on the Tomahawk river.

It is recommended that the Wisconsin State Board of Forestry co-operate with the Wisconsin Valley Improvement company in investigating future reservoir projects. To this end the suggestion is made that the Wisconsin Valley Improvement company be requested to invite the State Board of Foresry to co-operate with them in the investigation of future reservoir projects, and to have their consulting en-

gineer attend the meetings of the Board of Directors of the Wisconsin Valley Improvement company when future reservoir projects are being considered. In this way the State would keep in direct touch with new reservoir projects and would be informed without delay as to whether they were being developed to economical limits.

The question of ground storage in connection with future reservoir projects is very important. It is possible that there may be reaches of the river where small surface slopes exist and that by erecting dams, a considerable fluctuation of ground water extending over a large drainage area may be obtained. The apparent storage in such cases would be small, while the real storage would be large. The water held in ground storage would be free from evaporation and ideal conditions for storage would be provided.

Respectfully submitted,

C. B. STEWART.

MASS CURVES

showing the

YIELD OF THE WATERSHED OF THE UPPER WIS. RIVER

and

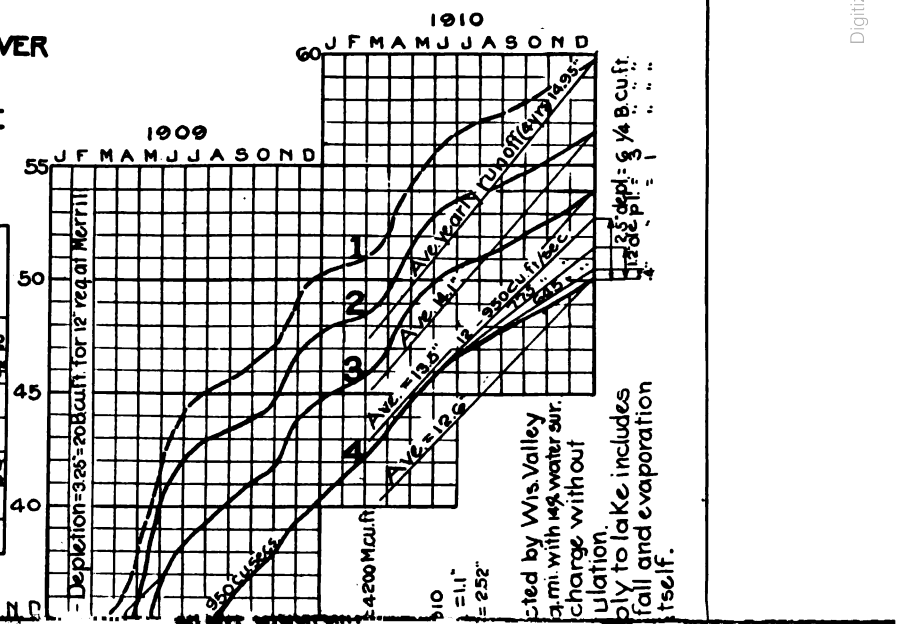
EFFECT OF VARIOUS AMOUNTS OF STORAGE

DRY YEARS 1907-1910

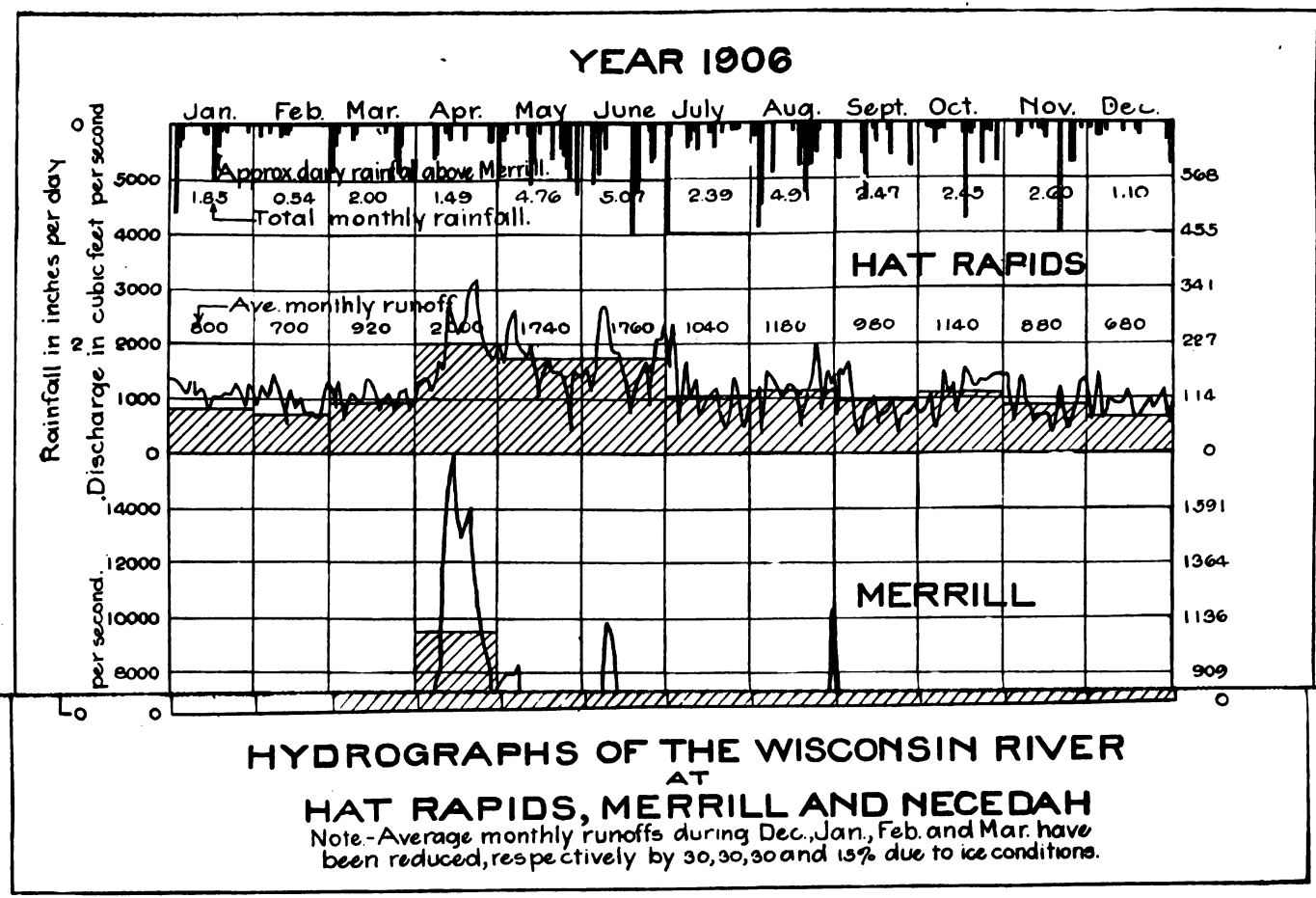
Explanation regarding curves

Curve No.	Runoff from watershed located	Approx drainage area in sq. mi.	Percent water surface	Remarks
1	Between H.R. & Merrill	1530	0	Approx. flow from land surface alone. Deduced from 2
2	" " "	1530	4	From daily gage readings
3	Merrill and above	2600	6 1/2	" " " "
4	Hat Rapids & above	1070	10	" " " "
5	Between H.R. & Merrill	1530	14	Deduced from No. 2 use for 560 sq. mi. under reg. by W.V. Co.
6	" " "	1530	25	Deduced from No. 2
7	" " "	1530	30	" " "

Note:-
The mass diagram affords



C.B. Stewart
Consult. Engr.
Madison Wis.

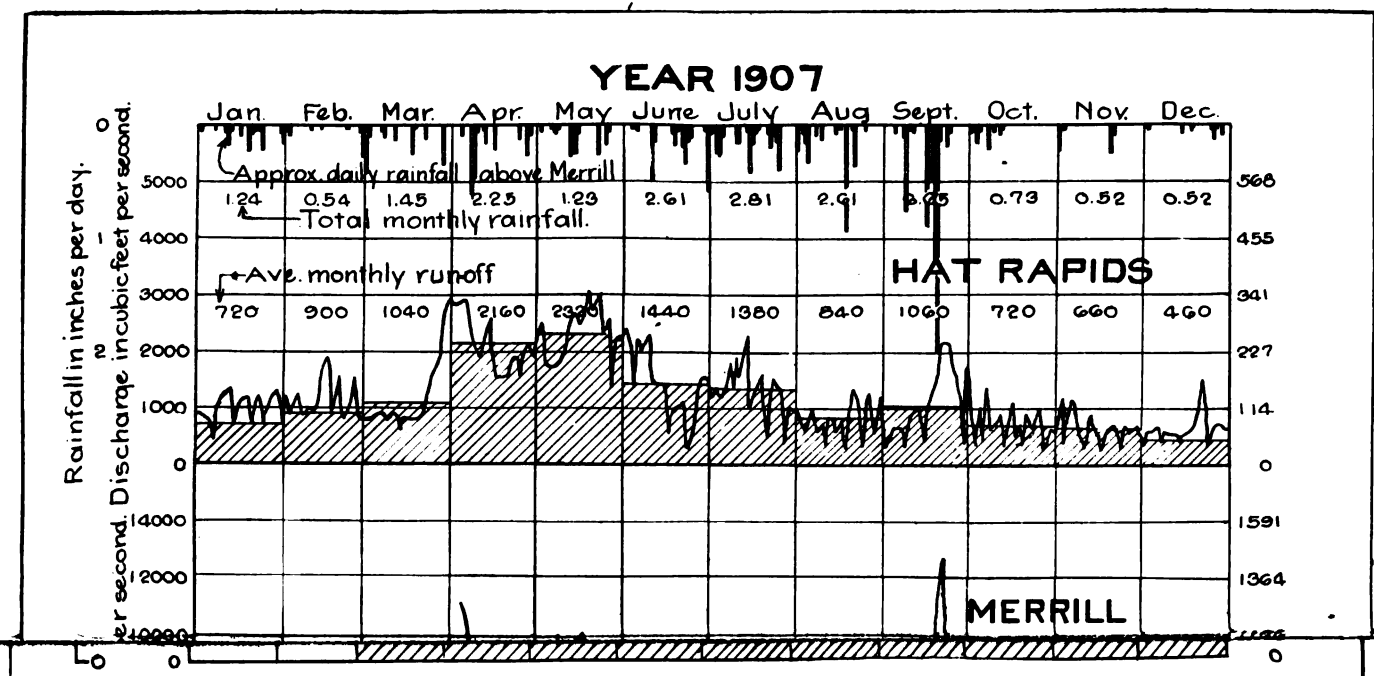


HYDROGRAPHS OF THE WISCONSIN RIVER
AT
HAT RAPIDS, MERRILL AND NECEDAH

Note.-Average monthly runoffs during Dec., Jan., Feb. and Mar. have been reduced, respectively by 30, 30, 30 and 15% due to ice conditions.

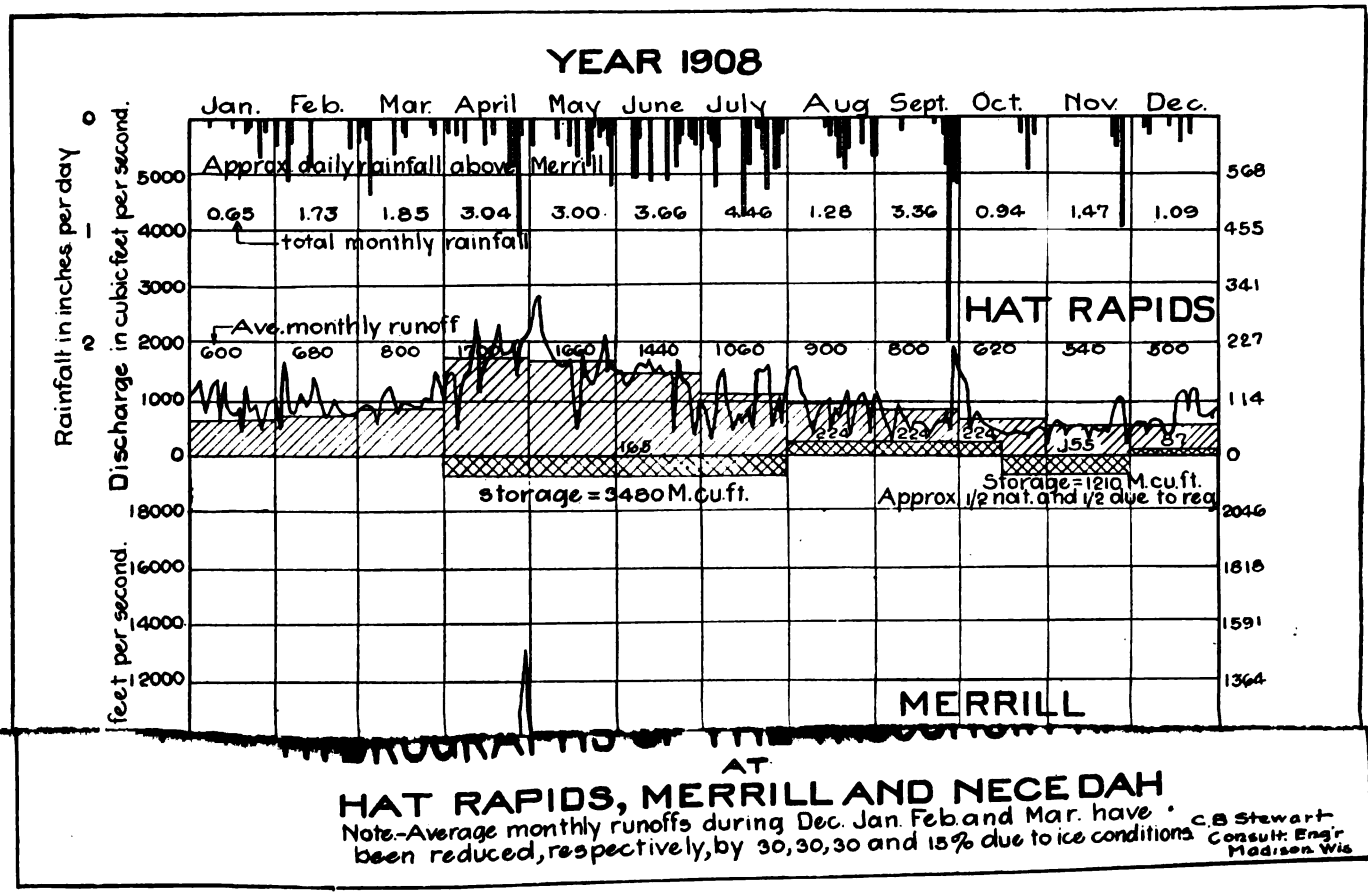
Note:—Drainage area above Hat Rapids = 1,070 sq. miles; above Merrill = 2,600 sq. miles; above Necedah = 5,800 sq. miles.

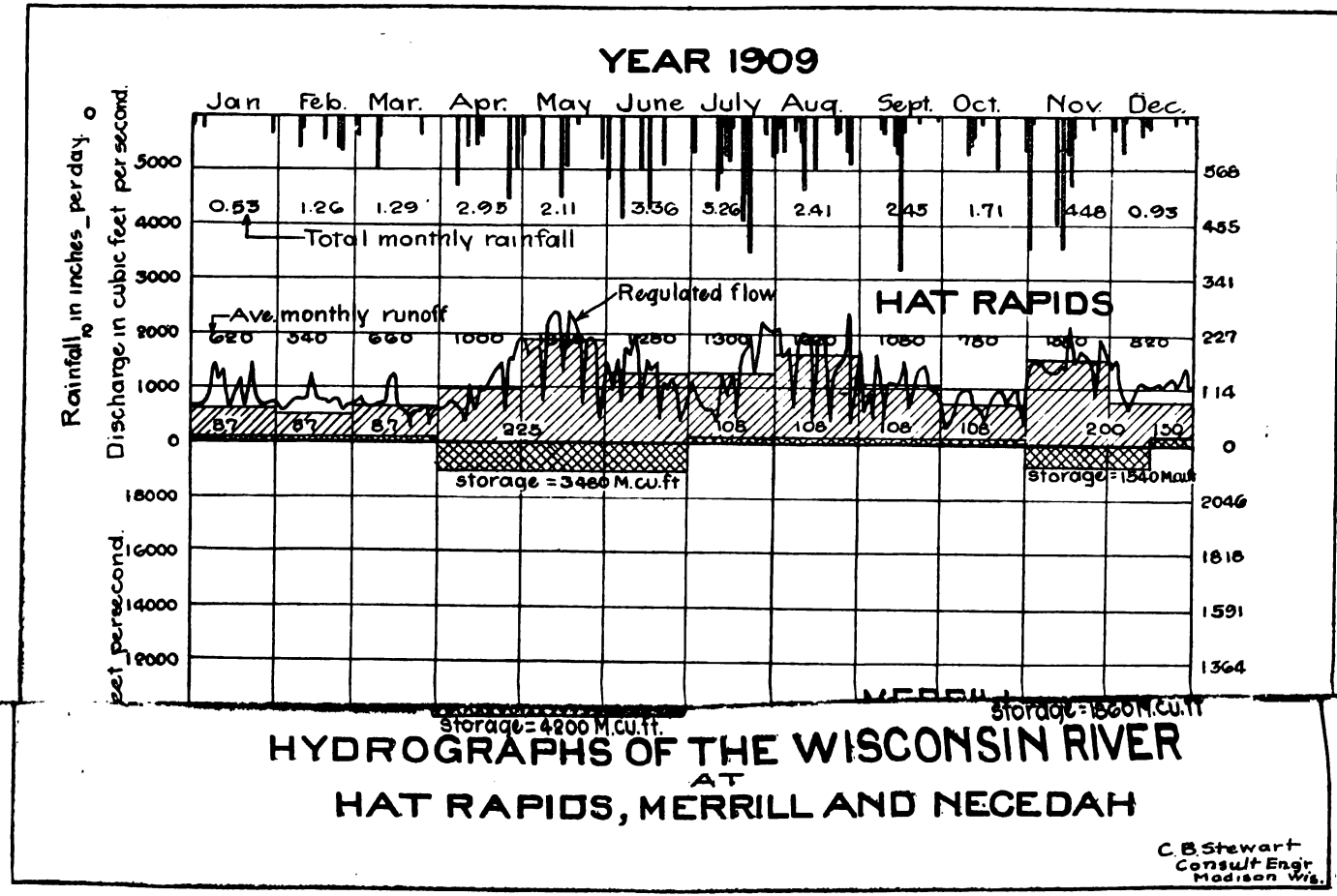
PLATE XXVI.



HYDROGRAPHS OF THE WISCONSIN RIVER AT HAT RAPIDS, MERRILL AND NECEDAH

Note:- Average monthly runoffs during Dec, Jan., Feb., and Mar. have been reduced, respectively, by 30, 30, 30 and 15% due to ice conditions.





HYDROGRAPHS OF THE WISCONSIN RIVER AT HAT RAPIDS, MERRILL AND NECEDAH

C. B. Stewart
Consult Engr
Madison Wis.

PLATE XXIX.

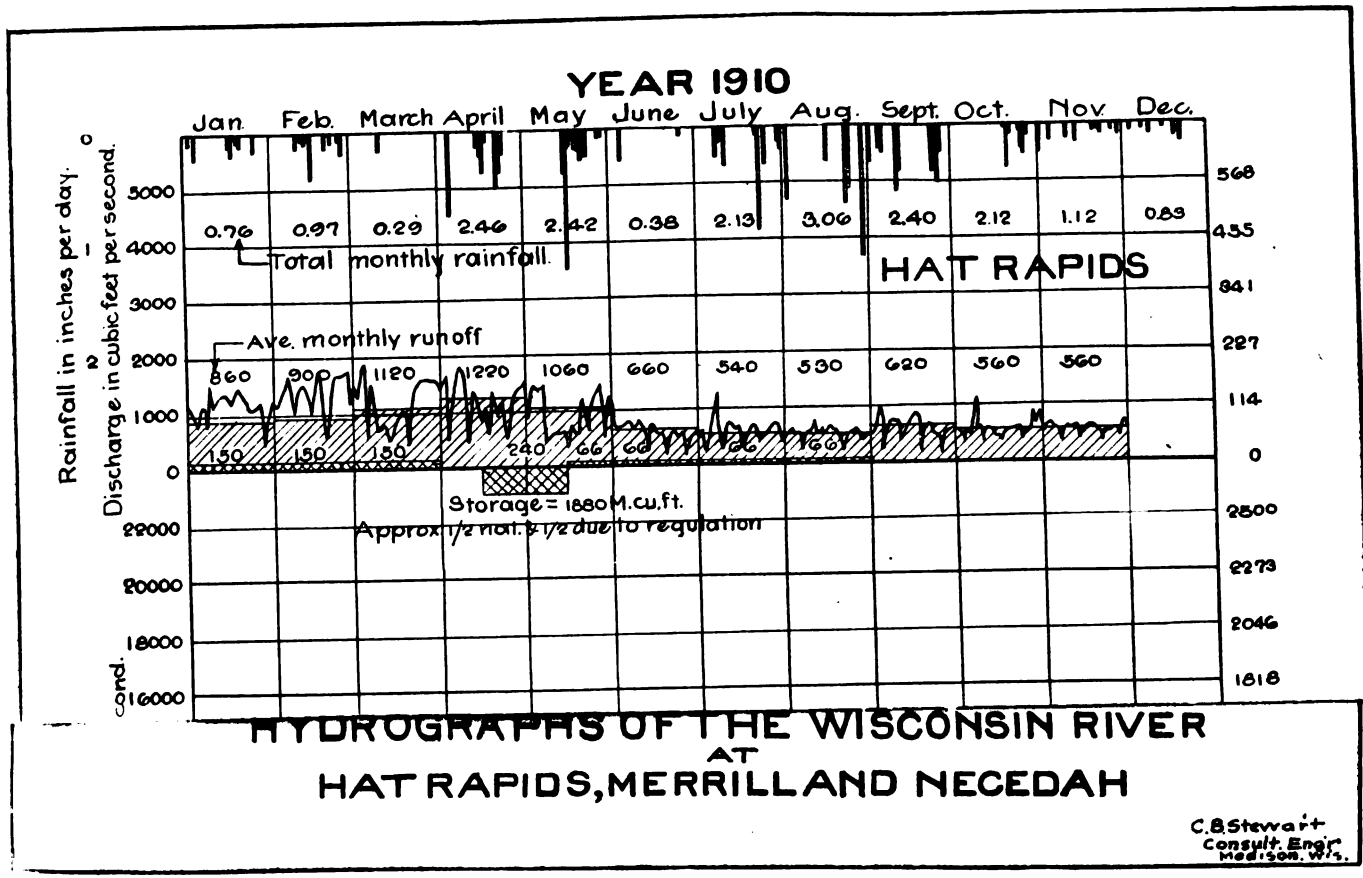
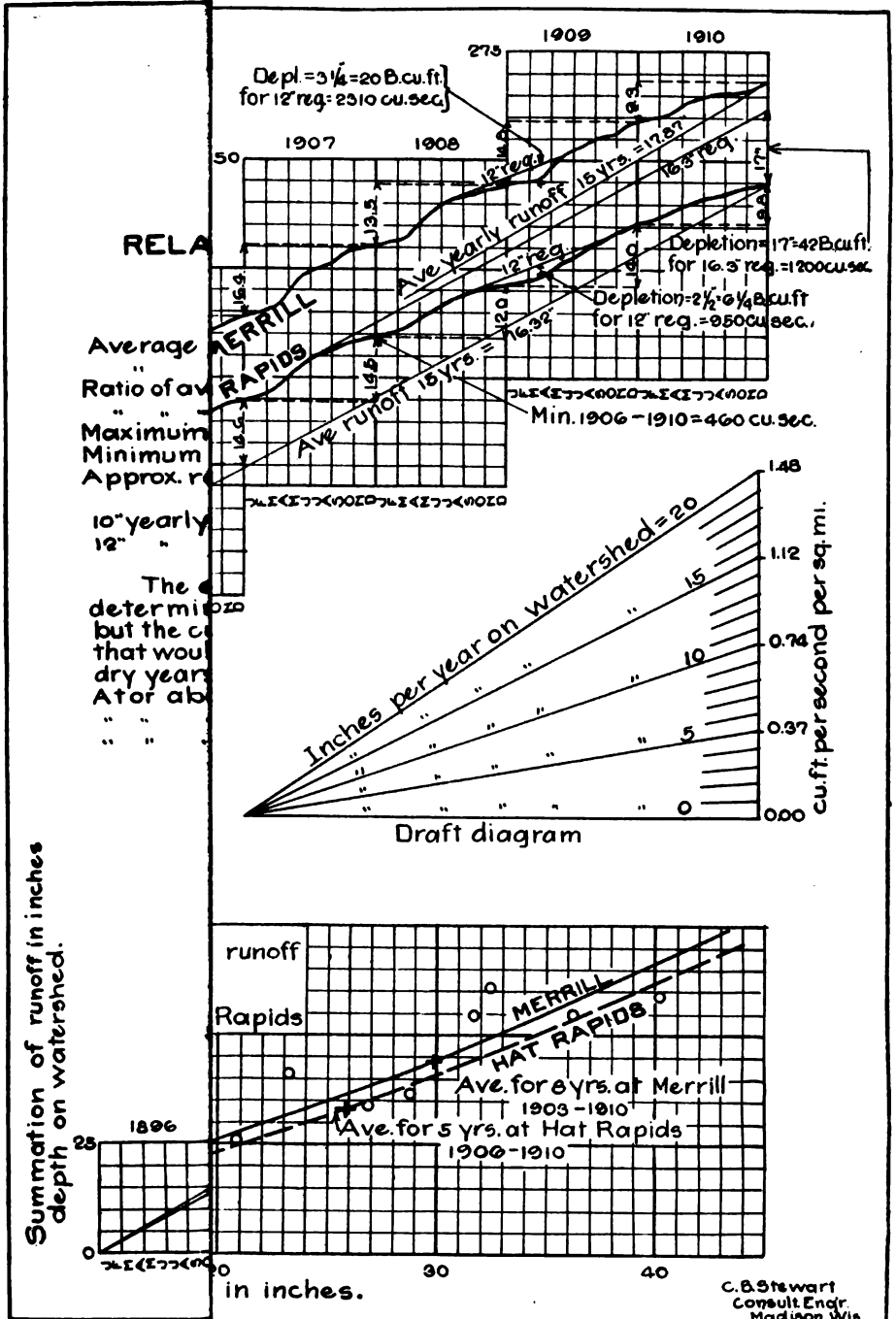

YEAR 1910
Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec.
Rainfall in inches per day.
Discharge in cubic feet per second.
Cond.
0.76 0.97 0.29 2.46 2.42 0.38 2.13 3.06 2.40 2.12 1.12 0.83
Total monthly rainfall.
HAT RAPIDS
Ave. monthly runoff
860 900 1120 1220 1060 660 540 530 620 560 560
150 150 150 240 66 66 66 160
Storage = 1880 M.cu.ft.
Approx 1/2 nat. & 1/2 due to regulation
568 455 341 227 114 0
2500 2273 2046 1818
HYDROGRAPHS OF THE WISCONSIN RIVER AT HAT RAPIDS, MERRILL AND NECEDAH
C.B. Stewart
Consult. Engr.
Madison, Wis.

PLATE XXX.



APPENDIX A.

REFERENCE TO AUTHORITY UNDER WHICH THE DAMS OF THE WISCONSIN VALLEY IMPROVEMENT COMPANY WERE ERECTED.

WAUSAU, WIS., October 7, 1910.

MR. C. B. STEWART,
Madison, Wisconsin.

DEAR SIR:—I have gone over the laws of Wisconsin somewhat carefully and find that the most of the dams in connection with our reservoirs have been erected by corporations which have been organized under Chapter 86 of the general laws of Wisconsin and acts amendatory thereof. I believe the following are the only ones that have been constructed in any way pursuant to special legislation:

First: Our dam at South Pelican, which was constructed under a contract between the Wisconsin Valley Improvement company and the Antigo Island club, a copy of which contract you have. This club had special authority to erect a dam under Chapter 26 of the laws of Wisconsin for 1903, a copy of which you already have. [See Appendix B.]

Second: Our dam at North Pelican, which in like manner was erected under a contract with Messrs. Barnes, Brown, Stapleton and Moen, a copy of which contract you have. [See Appendix C.] These gentlemen had special authority to erect a dam by Chapter 398, general laws of Wisconsin for 1905.

Third: Long Lake on Eagle, provision for which was originally given by Chapter 532 of the general laws of Wisconsin for 1887, and which is especially referred to in the Act of Legislature relating to our company, Chapter 335 of the laws of Wisconsin for 1907. The said dam was built by the Long Lake Improvement company, and our company owns all the stock of the old company.

Fourth: Our dam at Minocqua, erected by virtue of authority specially given by Chapter 252, general laws of Wisconsin for 1889. This act is also referred to in said chapter 335, laws of Wisconsin for 1907. The dam at this place was constructed by the Minocqua Dam company, a corporation duly organized pursuant to Chapter 86 of the Revised Statutes of Wisconsin, to which company all rights given to the parties named in said Chapter 252 had been duly assigned, and the entire stock of this company is also owned by the Wisconsin Valley Improvement company.

Fifth: Our dams at Big St. Germain and Little St. Germain, which as I understand it had been erected pursuant to original authority given by Chapter 355, laws of Wisconsin for 1883, and which rights have been fully acquired by our company. Should I at any time find that I am mistaken in this I will advise you.

Sixth: Our dam at Squirrel, which, as I understand it has been maintained pursuant to the authority given by Chapter 434, laws of Wisconsin for 1887, which rights have been fully acquired by our company.

All our other dams have been originally constructed by river improvement companies organized under Chapter 86 of the general laws of Wisconsin and acts amendatory thereof, and particularly under the provisions of Sections 1777 and 1777a, etc., contained in said chapter 86, and having special provisions for the organization of corporations formed in whole or in part for the improvement of streams, etc. These companies include the Vieux Desert Improvement company, which established its dam at that place, the Pioneer Improvement company with a dam at Twin Lakes, the Buckatabon Improvement company, with its dam at that place, the Deerskin River Improvement company with dams, as I understand it, at what is called Long Lake on Deerskin and Lower Deerskin, the Nine Mile Creek Improvement company, with its dams at Upper Nine Mile, Lower Nine Mile and Seven Mile, and the Sugar Camp Improvement company, with its dam at Sugar Camp. Our company owns the entire stock in all of these corporations.

Section 1 of said Chapter 335 of the laws of Wisconsin for 1907 especially gives the Wisconsin Valley Improvement company the right to acquire these properties.

I think you will find the foregoing information is complete, and all you will desire. Mr. Babcock has not yet returned, and I have had no opportunity to confer with him. As above stated, I have gone over the entire statutes relating to dam charters which have been granted by our state legislatures and I believe I have covered completely in the foregoing statement everything which relates to our reservoirs. As stated above, I shall be glad to furnish any further information you may wish. and if I find on Mr. Babcock's return I have omitted anything in this statement I will supply it. You will readily understand that I may have made some omission, and I know you will appreciate our willingness to furnish you all the information we possess in this entire matter.

Yours respectfully,

G. D. JONES,
Secretary.

APPENDIX B.

CONTRACT FOR NORTH PELICAN LAKE.

This deed and agreement made and entered into this 16th day of December, A. D. 1908, by and between the Farm Land Company, a corporation, Matt Stapleton, Alice Stapleton, W. E. Brown, J. O. Moen, John Barnes and Julia K. Barnes, his wife, parties of the first part, and the Wisconsin Valley Improvement Company, a corporation, party of the second part, to-wit:

(1) It is understood that the above named Matt Stapleton, Alice Stapleton, and John Barnes are the owners of Lots 4 and 6 of Section 4, Township 36 North of Range 10 east, in Oneida County, Wisconsin, and also of a dam across the North Pelican River situated upon said lots, and that said parties also own certain other lands adjacent to and abutting on the North Pelican chain of lakes, which said lands are hereinafter more particularly described.

(2) It is further understood that the Farm Land Company above named is likewise the owner of a considerable quantity of land adjacent to and abutting on said North Pelican chain of lakes, which said land is likewise more particularly hereinafter described.

(3) It is further understood that said Matt Stapleton, W. E. Brown, J. O. Moen and John Barnes are the owners of certain rights and franchises empowering them to maintain a dam not exceeding six feet in height across the Pelican River on certain lands therein described, and also empowering them to exercise the right of condemnation of such lands as might be overflowed by the maintenance of said dam, such rights and franchises being conferred by Chapter 398 of the General Laws of Wisconsin for the year 1905.

(4) That between Roosevelt station on the Minneapolis, St. Paul and Sault Ste. Marie Railway and the aforesaid dam on Section 4, Township 36, Range 10 east, a distance of several miles, there is a chain of lakes of great natural beauty connected by thoroughfares navigable for row boats and canoes even in stages of low water and navigable for small draught launches in moderately high water. That such chain of lakes is situated but a few miles from the city of Rhinelander, and is resorted to by a great many people seeking health, pleasure and

recreation, and there is already established a summer resort for the accommodation of the public on one of said lakes, as well as a considerable number of cottages that are privately owned. That in order to fully utilize said chain of lakes, and the thoroughfares connecting the same, for the purposes stated, it is necessary and advisable to improve the navigation thereof during the summer months, by maintaining a constant head of water therein sufficiently high to admit of their being navigated by small power crafts.

(5) That the first parties to this contract, individually and collectively, are interested in lands adjacent to and abutting upon said lakes, or in summer cottages thereon, or both, and the dam and franchises herein referred to were procured by them, not for purposes of direct financial profit, but to improve the navigability of said lakes and streams so as to develop them as health and pleasure resorts. That some of said lakes are quite shallow and in order to properly preserve the same it is necessary to maintain a dam at the outlet of the lower lake in said chain.

(6) That the defendant is a corporation, organized for the purpose, among other things, of acquiring flowage and water storage and water reservoir rights and privileges. That its stockholders consist principally, if not wholly, of persons who own or are interested in developed and undeveloped water powers on the Wisconsin River, and that its principal object and purpose is to store surplus water in the reservoirs controlled by it in time of high water, so that the same may be utilized for hydraulic purposes during dry portions of the year. That the aforesaid chain of lakes, together with the swamps and low ground adjacent thereto, cover a large area of territory and constitute a valuable storage basin. That the water in the Wisconsin River is generally lowest during the winter season, and the greatest necessity for using surplus water usually exists during the winter months, and the right to use the head of water created by said dam, during the winter months, and when the same is not necessary for the uses and purposes of navigation hereinbefore set forth, is exceedingly valuable to the water power interests upon said Wisconsin River, which rights said second party has been formed to conserve. That said dam can be so operated as to carry out the objects and purposes of the first parties hereto, and also in such a manner as to be of very material use and benefit to those interested in the second party to this contract.

(7) For the consideration, and subject to the conditions hereinafter set forth, said Matt Stapleton, W. E. Brown, J. O. Moen and John

Barnes, hereby sell, assign, transfer and convey to the second party, its successors and assigns, all rights, franchises and privileges conferred upon them by virtue of Chapter 398 of the General Laws of Wisconsin for the year 1905, the said grantee to assume the duties and obligations provided for in said act.

(8) For the consideration, and subject to the conditions hereinafter named, the Farm Land Company hereby sells, assigns, transfers and conveys to said second party the right to overflow the lands hereinafter described to such extent as the same will be overflowed by raising a head of water on said dam to a height hereinafter specified. The following is a list or schedule of lands intended to be covered by this paragraph of the contract: East half of the southeast quarter of section twenty-four; lots one, three, five and seven, and all that part of lot two now owned by said Farm Land Company, all in Section twenty-five, Township number thirty-seven North, Range number nine east, and lots three, four and six of Section thirty in Township number thirty-seven North of Range ten east.

(9) For the consideration of twelve hundred and fifty (1250) dollars, of which sum Matt Stapleton is to receive seven hundred and fifty (750) dollars and John Barnes is to receive five hundred (500) dollars, and in consideration of and subject to the other conditions hereinafter set forth, said Matt Stapleton and Alice Stapleton, and John Barnes and Julia K. Barnes, his wife, hereby convey and warrant, subject to 1908 taxes assessed against said lands, to said second party lots four and six of Section four in Township number thirty-six, north of Range ten east. Said last named parties further convey to said second party all their right, title and interest in and to the dam across the Pelican River located on said lots, and also all their right, title and interest in and to the stock, property rights and franchises of the Pelican River Improvement Company. Said last named parties further bargain, grant, sell and convey to said second party the right to overflow the lands hereinafter described, insofar as the same will be overflowed by raising a head of water on said dam to such a height as is hereinafter specified. The lands as to which such right is conveyed are the following: Lot nine of Section four; lots two and three, and an undivided one-third interest in lots seven and eight of Section five, and the southeast quarter of the southeast quarter of Section six, all in Township number thirty-six north of Range ten east. Lot two of Section thirty and lot two of Section thirty-one in Township num-

ber thirty-seven, north of Range ten east. It is understood that no part of said consideration of twelve hundred and fifty (1250) dollars is paid for the right to overflow said lands.

(10) Said second party, on its part, agrees to construct and maintain a good and substantial dam across the Pelican River upon lots four and six of said Section four, and further agrees to maintain a head of water on said dam, from June 1 to September 15 in each year, of such height that the water in the inlet to Moen Lake (being the upper lake in the North Pelican chain) shall be sixteen inches below the center of the cross sill in the bridge of the Minneapolis, Sault Ste. Marie and Atlantic Railway over and across said inlet as now maintained. It is understood and agreed that it may not always be possible or practicable to maintain a constant head of exact and uniform height, owing to evaporation and other causes, but the second party agrees to maintain said head and said height as near as it is possible or practicable so to do, and at no time within the period mentioned shall it be allowed to drop more than four inches below such point unless the evaporation is so great that such head cannot be maintained with the dam closed. In the event of such dam being destroyed by the elements, or by other causes beyond the control of the second party, said second party shall at once proceed to repair said dam and put the same in order with all reasonable diligence and dispatch. Said second party further agrees to secure the gates of said dam, and to watch the same so that the same will not be tampered with, and any surreptitious raising of the said gates or tampering therewith shall furnish no excuse on the part of the party of the second part for failing to maintain the head of water herein provided for. The provisions of this paragraph and of this agreement shall extend to and cover any dam or dams hereinafter built by the second party across the outlet of said North Pelican chain of lakes, and in such a place as to affect in any manner the head of water in such lakes, regardless of whether such dam is built above or below or upon the present dam site.

(11) It is the purpose and intention of the parties to this contract that the first parties, or a majority of them, shall have the absolute right to dictate the height of water that shall be held upon said dam or upon any dam to be hereinafter built, between June 1 and September 15 in each year. If, after the water has been held at the height herein specified for one season or for a part of a season, it shall appear that the point herein designated as the one at which water is to be held is not the proper one, then said first parties or a majority of them

shall have the right to designate another and a different point, and the point so designated shall be marked by some substantial monument upon the shore line of said Moen Lake, and said second party agrees to enter into a new contract with said first parties fixing and definding such new point, if requested so to do by said first parties or a majority of them.

(12) The flowage rights herein conveyed by the parties of the first part shall be confined and limited to such land as will be overflowed by maintaining a head of water on said dam not to exceed twelve inches above the point designated in this contract as the one at which said head of water is to be held as constantly as possible from June 1 to September 15 in each year; it being conceded, as far as the first parties are concerned, that such extra head may be held at other seasons of the year.

(13) No consideration has been paid to said Matt Stapleton, W. E. Brown, J. O. Moen or John Barnes, for the assignment of the franchise herein conveyed, except the agreement on the part of the second party to maintain the head of water herein provided for between June 1 and September 15 in each year. It is expressly agreed that, in the event of the failure of the second party to maintain such head as herein provided, then and in that event said second party shall forfeit all right, title and interest in and to said franchise rights and privileges, and the same shall revert to and become the property of said Matt Stapleton and John Barnes, being the parties who own and are by this instrument conveying the land upon which said dam is located and are the parties best situated by reason of such ownership to utilize such franchise; and thereafter said second party shall not maintain or attempt to maintain any dam that will in any manner affect the head of water in said lakes.

(14) It is further understood that no consideration has been paid said Farm Land Company for the flowage rights hereby conveyed, except the agreement made by the second party to maintain the head of water from June 1 to September 15 in each year, herein provided for, and it is agreed that in the event of the failure of said second party to maintain such head, all such rights, easements and property as is hereby conveyed shall revert to and become the property of said Farm Land Company, and all right to overflow said lands, in any manner, by the second party, its successors or assigns, shall cease.

(15) It is further agreed and understood between the parties hereto that a large and material part of the consideration for the conveyance

of the lands, flowage rights and other property conveyed by this instrument, by said John Barnes and Matt Stapleton and their respective wives, is the agreement on the part of the second party to maintain a head of water on said dam, or any dam or dams hereafter to be built, between June 1 and September 15 in each year, of the height herein provided for, and that in case said second party, its successors or assigns shall not keep and maintain said head of water conformably to the terms of this contract, the two lots hereby conveyed outright, the dam thereon, all flowage rights and all property rights or franchises of every name and nature hereby granted or conveyed to said second party by said last named first parties as well as all franchises hereinafter obtained enabling said second party to operate and maintain said dam, shall revert to and become the property of said Matt Stapleton and John Barnes, and all rights of said second party, its successors or assigns, of, in or to said property or any part thereof, shall cease and terminate; provided, however, that the failure to maintain the head agreed upon shall not work a forfeiture as to any of said first parties in the event of said dam being carried away by the extraordinary action of the elements or other causes beyond the control of said second parties if such dam is replaced with due and reasonable diligence.

(16) The forfeitures herein provided for shall be deemed self-executing, and a failure on the part of said second party, its successors or assigns, to comply with the terms of this contract, shall divest said grantee or its successors or assigns of the property rights and franchises herein conveyed or described, without any act or declaration on the part of said grantors, their heirs, successors or assigns, and said first parties shall thereupon have the right to take possession of such property and to use and enjoy the same without let or hindrance from said second party, its successors or assigns.

The covenants herein contained shall be mutually binding upon the parties hereto and their respective heirs, successors and assigns.

In Witness Whereof the individuals who are parties hereto have signed their names and affixed their seals this 16th day of December, A. D. 1908, and the corporations who are parties hereto have caused this deed and contract to be signed by their respective presidents and countersigned by their respective secretaries, pursuant to authority duly conferred upon such officers by the respective boards of directors

of the corporations which such officers represent, and have caused their respective corporate seals to be attached the day and year above written.

Witnesses as to Matt Stapleton, Alice Stapleton, W. E. Brown, J. O. Moen and Farm Land Company.	MATT STAPLETON, (Seal)
	ALICE STAPLETON, (Seal)
	W. E. BROWN, (Seal)
	J. O. MOEN. (Seal)
Grover Stapleton,	FARM LAND COMPANY,
Helen Stapleton.	By J. O. MOEN, President,
Witnesses as to John Barnes and Julia K. Barnes.	CHAS. B. PETERSON, Secretary.
	JOHN BARNES. (Seal)
	JULIA K. BARNES. (Seal)
Fayne Barnes,	WISCONSIN VALLEY IMPROVEMENT COMPANY.
John K. Barnes.	
Witnesses as to the Wisconsin Valley Improvement Co.	By GEO. A. WHITING, President.
Margaret Ryan,	G. D. JONES, Secretary.
Clyde Weik.	

(The above signatures were duly acknowledged).

APPENDIX C.

CONTRACT FOR SOUTH PELICAN LAKE.

KNOW ALL MEN BY THESE PRESENTS, That the undersigned, ... and ..... his wife, being the owners of the following described lands bordering on Pelican Lake in Oneida County, Wisconsin, to-wit:

.....

.....

.....

do hereby for a valuable consideration give and grant unto the Wisconsin Valley Improvement Company and its successors and assigns, the right so far as the exercise of the same affects the lands aforesaid to construct and perpetually maintain and operate a dam across the outlet of said lake and therewith maintain the water in said lake at the high water mark of said lake as ascertained in October, 1907, by representatives of the Antigo Island Club and of said company and agreed to be established at one and one-half inches above the highest surface of that certain large rock lying in the water at the most

southwesterly extremity of the Antigo Island Club's island in Pelican Lake marked on the upper surface with the following design cut in said rock, viz: a square, marked, 1½ and to be further marked by another monument at the same elevation at such point on said lake as the grantors shall determine.

This grant is made upon the express condition that the said company shall construct and complete said dam within one year; shall maintain said dam in good condition for operation and have at all times a competent man in charge thereof and shall maintain the water in said lake at all times between April 1st and November 1st of each year as nearly as practicable at or within six inches below said high water mark and shall not draw down the water in said lake lower than two feet below said high water mark during the balance of the year. In case said conditions be not complied with this instrument shall be void.

Witness our hands and seals this ..... day of ....., 1908.
In presence of:

....(Seal)
....(Seal)

State of Wisconsin,)
)ss.
Langlade County.)

Personally came before me this.....day of....., 1908, the above named..... and ....., his wife, to me known to be the persons who executed the foregoing instrument and acknowledged the same.

.....,
Notary Public for Wisconsin.

My commission expires.....